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International trends in technological progress: stylized facts from patent citations, 1980-2011

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cemmap working paper CWP16/14

INTERNATIONAL TRENDS IN TECHNOLOGICAL PROGRESS: STYLIZED FACTS FROM PATENT CITATIONS, 1980-2011

SOONWOO KWON¹, JIHONG LEE¹, AND SOKBAE LEE^{1 2}

ABSTRACT. We analyze cross-country trends in technological progress over the period of 1980-2011 by examining citations data from almost 4 million utility patents granted by the US Patent and Trademark Office (USPTO). Our estimation results on patent quality and distance to the knowledge frontier reveal the following stylized facts. The emerging Asian economies of Korea, Taiwan and China have indeed achieved substantial catch-up towards the technology frontier. In the case of Korea and Taiwan, progress has been made in terms of patent quality as well as distance to the frontier. Chinese patents are of higher quality now than before but Chinese inventors have yet to reduce the citation lag relative to the frontier. In contrast, advanced economies of Europe and Japan have displayed steady decline in their patent quality. Finally, the US has maintained, and in some cases strengthened, its position as the world technology frontier.

KEYWORDS: Innovation, patent citation, patent quality, distance to the knowledge frontier, international comparison

JEL CLASSIFICATION: O33, O57

1. INTRODUCTION

Innovation is the main engine of long-run economic growth. In a frictionless world where knowledge spills over freely, there would be no cross-country differences in technological progress and hence long-run growth; however, substantial variations across and within economies have existed in the real world. The purpose of this paper is to document comprehensive cross-country trends in technological progress by examining US patent citations

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data for the period of 1980-2011. We update existing citations datasets to facilitate analysis of the most recent trends.

Since 1980, about half of patents taken out at the United States Patent and Trademark Office (USPTO) have come from inventors residing outside the US. Traditionally, Japan, Germany, France and Great Britain have been important originating countries of USPTO-granted patents. Recently, Taiwan and South Korea have joined the ranks of top patent-producing nations, while a rapidly increasing number of USPTO patents now belong to China. Table 1 summarizes top 15 countries in terms of all USPTO utility patent counts by the country of the first inventor between 1980 and 2011.¹

TABLE 1. Patent Counts

Country	Period								Total
	1 (1980- 1983)	2 (1984- 1987)	3 (1988- 1991)	4 (1992- 1995)	5 (1996- 1999)	6 (2000- 2003)	7 (2004- 2007)	8 (2008- 2011)	
United States (US)	143344	159569	189250	217289	287008	347796	328568	376725	2049549
Japan (JP)	32454	53622	76877	88366	108176	134985	136054	160464	790998
Germany (DE)	23031	27781	30999	27533	32258	44226	38851	42235	266914
EU	11946	14926	17313	16721	22782	30533	26628	31467	172316
France (FR)	8138	9805	11697	11538	13240	15766	12815	15294	98293
Great Britain (GB)	8940	9943	11262	9432	12167	15107	13463	14877	95191
Taiwan (TW)	298	824	2686	5253	10747	20777	23546	30026	94157
Korea (KR)	65	201	886	3421	10205	14581	20994	40305	90658
Canada (CA)	4206	5456	7344	8020	10811	13889	13163	16922	79811
Switzerland (CH)	4668	4992	5227	4549	4759	5419	4524	5597	39735
Australia (AU)	1086	1395	1812	1713	2376	3352	4467	6189	22390
Israel (IL)	459	775	1166	1383	2515	3973	4284	6369	20924
China (CN)	5	35	196	204	270	894	2222	8709	12535
India (IN)	28	52	73	118	279	897	1773	3651	6871
Former Soviet Union (FSU)	1264	598	609	364	726	968	836	1121	6486
Rest of the world (RW)	2406	2699	2941	2977	4314	7131	7577	10275	40320
Total	242338	292673	360338	398881	522633	660294	639765	770226	3887148

Notes: Data consist of all utility patents granted at the United States Patent Office (USPTO) between 1980 and 2011. A country of a patent is classified by the location of the first inventor. EU refers to 15 European Union members as of 2002 except Germany, France, and Great Britain.

Table 1 confirms the meteoric rise in knowledge production by the emerging Asian countries of Korea, Taiwan, China and India. Interestingly, it also shows that the volume of patents has been rising for every country during the 1990s and 2000s. In particular, the

¹Roughly 99% of all relevant patents in the sample period originated from the top 15 countries.

number of patents by US inventors during the final 4-year period of 2008-2011 is more than two and a half times that of the initial period of 1980-1983; Japan, the second largest patent-producing country in 1980, saw a five-fold increase over the same time span. Other advanced countries of Europe (Germany, EU, France and Great Britain) are also producing substantially more patents now than before.

Despite this seemingly apparent global success in technological progress, serious concerns have been raised against the actual substance behind the recent surge in the volume of patents. In particular, Jaffe and Lerner (2004) argued that policy shifts in the US in the 1980s led to reduced costs of patent application on the one hand and a shortage of qualified examiners on the other, culminating in an exponential rise in the volume of USPTO-granted patents with lower average quality.² Ample evidence also exist to suggest similar quality decline in patents from the European Patent Office (EPO), the other major patent-granting body.³ In order to obtain more accurate gauge of the overall strength of technological progress, therefore, one must account for the quality of patents.

While the quality of innovation has been widely recognized for its important role in determination of economic growth (e.g. Grossman and Helpman (1991), Aghion and Howitt (1992)), there exists an intrinsic difficulty in its coherent measurement across countries and over time. Countries are highly heterogeneous and underlying factors affecting innovation are changing constantly. In this paper, we aim to establish stylized facts on international technological progress based on rigorous analysis of patent data. We overcome the issue of country-wide heterogeneity by focusing on USPTO-granted patents and address the time-varying nature of USPTO practices by adopting the method of difference-in-differences.⁴

²See Jaffe and Lerner (2004) for various examples of USPTO-granted patents with dubious merits. See also Federal Trade Commission (2003) and Merrill, Levin, Myers, et al. (2004) for declining quality of USPTO-granted patents.

³See, for example, Eaton, Kortum, and Lerner (2004), Guellec and de La Potterie (2007), Jones (2009), Griffith and Miller (2011) and OECD (2011).

⁴Formal models of growth that endogenize and estimate the development of innovation using patent data include Caballero and Jaffe (1993) and Eaton and Kortum (1996, 1999).

Since the study of Trajtenberg (1990), the citations data have offered an important source of patent quality measure: higher quality patents should generate more impact and hence more citations. The first part of our analysis studies the patent quality of different countries as measured by citations received within two years. Specifically, we develop a panel regression model with fixed effects to compare the patent quality of non-US inventors to that of US inventors in each of the three decades, 1980s, 1990s and 2000s. Using multiple measures of patent quality based on citations information, our regression analyses establish the following stylized facts:

- Patent quality of the emerging Asian economies of Korea and Taiwan caught up with the US during the 1990s, while similar catch-up occurred for China during the 2000s.
- Patent quality of the advanced nations of Europe and Japan declined relative to the US.
- The US maintained highest patent quality.

Our empirical analysis demonstrates that the rapid rise of Korea, Taiwan and China in patent production can indeed be substantiated by underlying quality improvement. On the other hand, our results throw caution to the possible conclusion from Table 1 that innovation has been advancing in other countries, in particular, the traditional powerhouses of Europe and Japan. When measured vis-à-vis the US, patent quality of these countries have declined during the sample periods. In the case of Japan, whose patent volume increased most among the advanced nations, the initial advantage over the US in patent quality was wiped out by the 1990s and turned into deficit in the 2000s. Perhaps most interestingly, the US continued to be the country of highest patent quality and even strengthened its relative advantage against many countries over the last several decades.⁵

⁵Another country that displayed a rapid increase in the volume of patents since 1980 is India. But, our regression results do not show clear improvement in India's patent quality.

The patent citations data offer another avenue to obtain an output indicator of innovation activity by different countries. Our idea is that an inventor who is quicker at citing the frontier technology is more likely to be closer to the frontier itself and hence in possession of superior innovation capacity. In the second part of our paper, we examine this idea by directly estimating the distance to knowledge frontier across countries during the sample period. By taking US-inventors' patents as the frontier technology, we adopt the fixed-effects estimator of Griffith, Lee, and Van Reenen (2011) to measure the speeds with which non-US inventors cite the frontier patents relative to US-inventors, which we refer to as "citation lag". Examining the trends, the citation lags for the advanced countries of Europe and Japan vis-à-vis the US did not change significantly over the last three decades. The main observation is the following:

- Most significant gains in narrowing of the distance to the knowledge frontier were made by the emerging economies of Korea, Taiwan and Israel.

Therefore, the technological progress of Korea and Taiwan have indeed been achieved on multiple dimensions. Israel's patent quality was much closer to the US than Korea and Taiwan in the early 1980s, and our evidence does not suggest any improvement in this dimension for Israel. China, for whom our evidence on patent quality trends suggest significant upgrade, did not register meaningful improvement on citation lag.

The literature on investigating patents as economic indicators is large and extensive.⁶ Among this literature, an early study on using patent citations as a quality indicator was by Trajtenberg (1990), who estimated the effect of various research inputs on the citation-weighted patent counts.⁷ An index of patent quality using citations information was developed by Lanjouw and Schankerman (2004). Also, a number of studies report a positive relationship between patent citations and market value of the patent holder (e.g. Bloom and Van Reenen (2002), Hall, Jaffe, and Trajtenberg (2005), Belenzon (2012)).

⁶See Griliches (1990), Jaffe and Trajtenberg (2002) and Hall and Harhoff (2012), among others.

⁷For another early application of citation data, see Lieberman (1987).

Another area in which patent citations have been used extensively is the literature on knowledge diffusion. Using patent citation information as a direct measure of the transfer of knowledge, this empirical literature explores the role of distance, e.g. national boundaries. See Jaffe, Trajtenberg, and Henderson (1993), Jaffe and Trajtenberg (1999), Thompson and Fox-Kean (2005), Henderson, Jaffe, and Trajtenberg (2005), Thompson (2006) and Griffith, Lee, and Van Reenen (2011), among many others.

In contrast to the aforementioned papers that explore patent citations data to measure knowledge spillovers, this paper uses citations to track the recent cross-country trends in technological progress. Unlike usual scientific citations, patent citations are often inserted at the request of examiners who set the boundaries of the new patent and note its context. While this raises a concern over the extent to which examiner-added citations measure knowledge spillovers (e.g. Jaffe, Trajtenberg, and Fogarty (2000)),⁸ such concerns are less likely to apply for measuring patent quality and distance to the knowledge frontier. Examiner-added citations may offer more objective evidence of patent quality and also how close a new patent has come to challenge the cited patent.

Another important distinguishing feature of our paper is the dataset. While most of the previous related studies were based on the citations data only up to 1999 (compiled by NBER) or sometimes up to early 2000s (using, for instance, Bronwyn Hall's dataset that goes up to 2002), we have updated the dataset up to 2011. This enabled us to obtain valuable insights into the global innovation trends in the most recent decade, including the growth of China which was not picked up previously.

Our paper also contributes an old debate on growth accounting and total factor productivity (TFP) in East Asia. During the 1990s, a number of authors (e.g. Young (1995), Page (1994)) concluded that the rapid growth of the four Asian Tigers (Hong Kong, Singapore, South Korea, Taiwan) up to 1990 was almost entirely *quantity*-driven. Our analysis

⁸Thompson (2006) used variation between citations added by examiners and by inventors to identify localized knowledge spillovers.

presents micro-level evidence that indeed suggests the occurrence of *quality*-driven growth by these countries, as well as China, since the 1990s.

Finally, we contribute to the literature on innovative activities in Asia. This literature sought to explain, among other things, the pattern of knowledge diffusion into and within the emerging Asian economies (e.g. Hu and Jaffe (2003), Hu (2009)) and the role of innovation behind their successful growth (e.g. Hu and Mathews (2005), Hu and Jefferson (2009), Griffith and Miller (2011), Lee (2013)). We offer not only comprehensive trends of technological progress by Asian economies using an updated dataset but also those of other important patent-producing countries outside Asia.

The remainder of the paper proceeds as follows. In Section 2, we describe our data. In Section 3, we study cross-country trends in patent quality by employing differences-in-differences estimation against the US benchmark in different time periods. In Section 4, we measure distance to the knowledge frontier, using the fixed-effects estimator of Griffith, Lee, and Van Reenen (2011), and document the trends across countries. Section 5 offers some concluding remarks. Appendices provide further details on our dataset as well as additional analyses that are left out of the main text for expositional reasons.

2. DATA

We use USPTO patent citation data from January 1980 to December 2011. The data up to 1999 are obtained from the National Bureau of Economic Research (NBER) U.S. Patent Citations Data Files – specifically, PAT63_99 and CITE75_99.⁹ Bronwyn Hall provides the corresponding data for additional three years, over the period 2000-2002, in her website.¹⁰ For this paper, we have extended the dataset up to December 2011 by extracting related

⁹These datasets have been widely used in the economic analysis of knowledge spillovers. See Hall, Jaffe, and Trajtenberg (2001) for an overview.

¹⁰Hall's augmented datasets – specifically, PAT63_02 and CITE75_02 – comprise of all 3,416,957 utility patents granted by the USPTO between January 1963 and December 2002 by the USPTO and all 22,309,440 citations made by utility patents granted in the period of January 1975 to December 2002. Hall's datasets are available at <http://elsa.berkeley.edu/~bhall/patents.html>.

information (including the inventor location) from the bulk data provided by the USPTO. Appendix A presents the details of how this data extension was conducted. Combining the two previous sets of data with our data extracts, we constructed a dataset consisting of all utility patents granted up to December 2011 and detailed information on the patents that cited other patents included in the dataset. The number of patents that we have added for the period of 2003-2011 amounts to over 1.5 million, equivalent to almost 40% of the sample size.

Our analysis considers top 15 countries in terms of the accumulated number of granted patents between 1980 and 2011.¹¹ These 15 countries, ordered from the most granted to the least, are as follows: United States (US), Japan (JP), Germany (DE), EU,¹² France (FR), Great Britain (GB), Taiwan (TW), Korea (KR), Canada (CA), Switzerland (CH), Australia (AU), Israel (IL), China (CN),¹³ India (IN) and Former Soviet Union states (FSU).¹⁴ Our estimation analyses below also consider patents produced by the rest of the world (RW).

3. MEASURING INNOVATION VIA PATENT QUALITY

The patent data offer a natural source for exploring the innovation capacity of a country. In this section, we analyze cross-country trends in patent quality measured by citations.

3.1. First Look. Figure 1 shows the cross-country trends in the “citation frequency”, i.e. the proportion of patents that were cited within two years from their grant dates across the 15 inventor locations (countries). Here, we take the US as the technology frontier, and its trend as a benchmark, and evaluate relative performance of the other countries. In each graph, the dashed line depicts the US benchmark trend.

¹¹Prior to 1980, there were only very few patents from the emerging economies of China, India, Korea, Taiwan and others. We therefore begin our analysis from 1980.

¹²EU consists of the following 12 countries: Austria, Belgium, Denmark, Finland, Greece, Ireland, Italy, Luxembourg, Netherlands, Portugal, Spain and Sweden, as in Griffith, Lee, and Van Reenen (2011).

¹³Hong Kong is excluded from China. In Appendix A, we explain how the location of the first inventor of a Chinese patent was checked in this regard.

¹⁴For consistency throughout the periods, we regard all patents whose inventors were located in the 15 former Soviet Union member countries as “FSU (Former Soviet Union)” patents.

FIGURE 1. Proportion of patents cited within 2 years

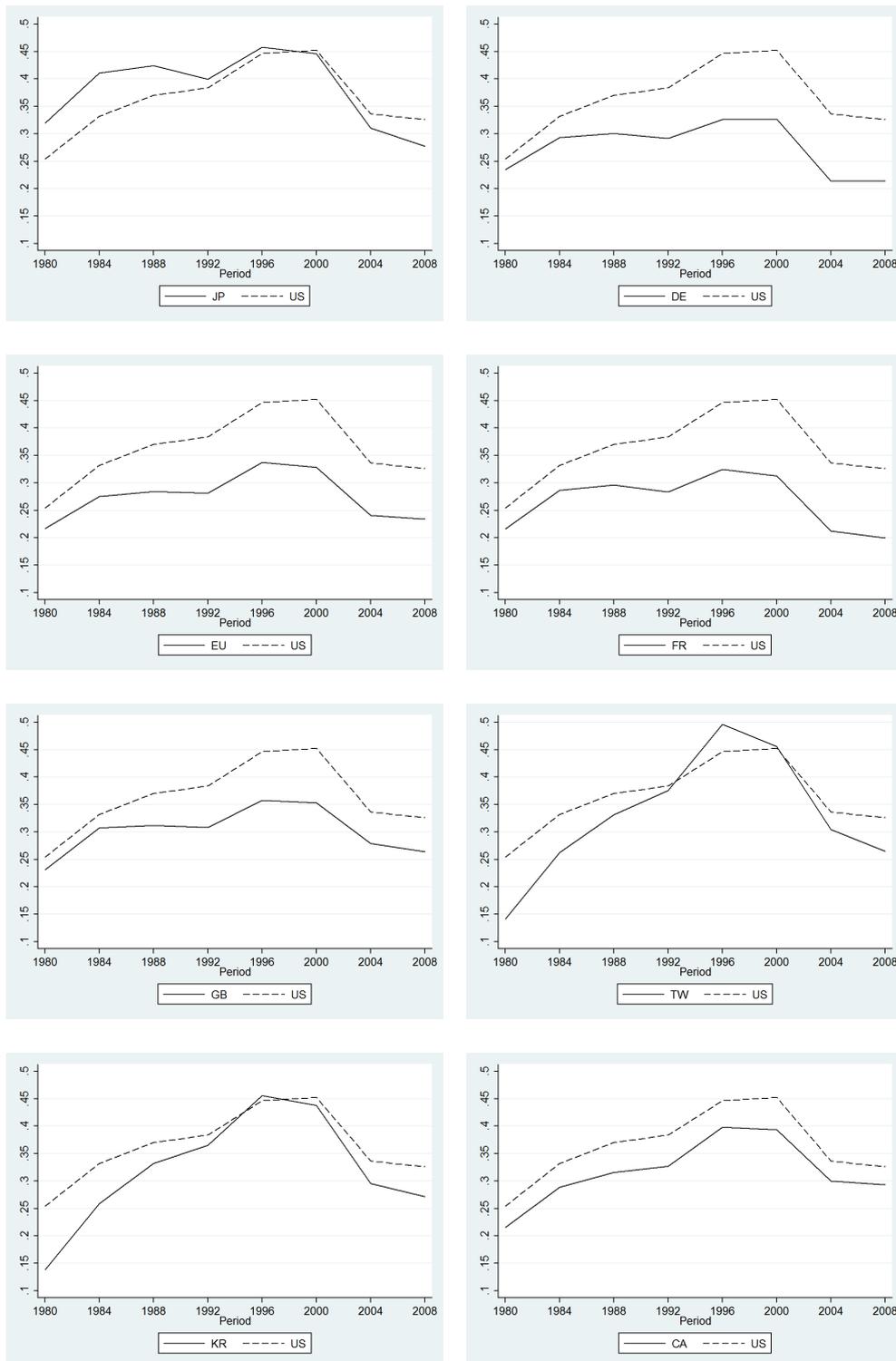
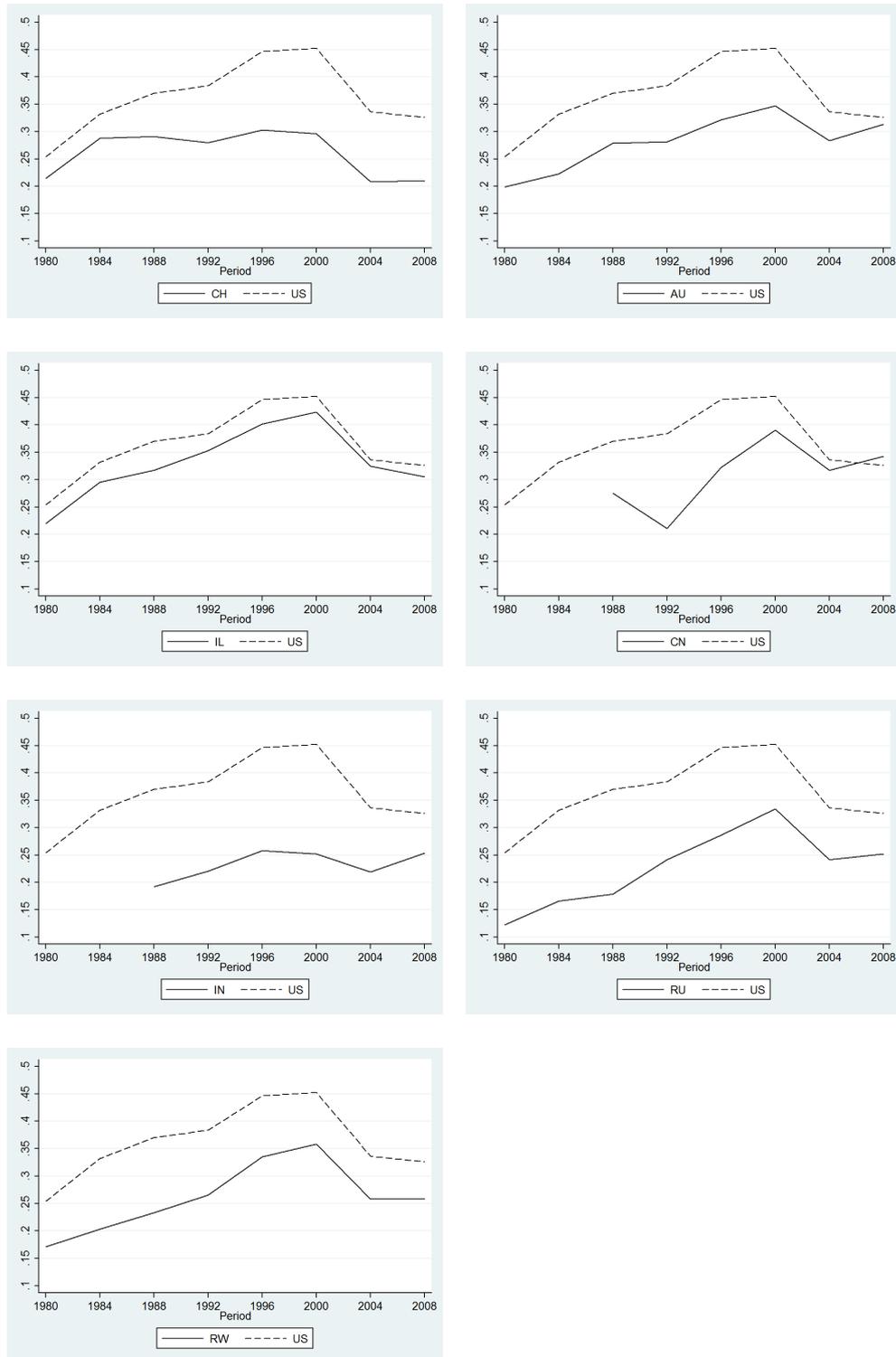


FIGURE 1. Proportion of patents cited within 2 years (continued)



Notes: The sample period 1980-2011 is divided into 8 sub-periods; each of the first 7 sub-periods is 4 years in length and the last sub-period is the 2 years between 2008-2009 to allow for a full 2-year window for forward citations. Each graph displays for each sub-period the proportion of patents cited within 2 years. Each graph includes the trends of the given country and the US benchmark.

There are several interesting facts to note from Figure 1. First, within the period of 1980-2011, the most notable surge in citation frequency was produced by the emerging Asian nations of Korea, Taiwan and China. Over the two decades up to 2000, patents granted to Korean and Taiwanese inventors went through an increase of more than 30%, while for other countries the corresponding figures ranged between 10 and 20 %. In the 2000s, a similar growth pattern was experienced by China.

Second, the advanced nations—the European countries (Germany, EU, France, Great Britain and Switzerland) and Japan—exhibited declines in citation frequency relative to that of the US. For the European countries, the gap against the US widened substantially over the period; for Japan, the initial advantage over the US was reversed and a substantial deficit emerged.

Third, and perhaps most importantly, the data reveal sustained prominence of the US in innovation quality measured by patent citation frequency. Its benchmark trends consistently lie above those of all other countries with few exceptions. The rapid improvements shown by Korea and Taiwan resulted in actual overtaking around the mid-90s but this was followed by relative decline in the 2000s, similarly to the pattern experienced by Japan. China's citation frequency reached parity with the US towards the end of the last decade.

Note that the above measure of citation frequency focuses only on whether or not a patent has been cited within a two-year window. While it is natural to think that cited patents are more likely to be of higher quality than non-cited patents, one might argue that there are other important citation measures correlated with the patent quality, for example, the average number of citations received. Also, Figure 1 demonstrates citation patterns for all industrial sectors; there might be meaningful variations if instead we compared the countries in different sectors separately. Therefore, we next conduct a more rigorous and comprehensive regression analysis of the cross-country trends in patent quality. In addition to citation frequency, our regression model also takes as dependent variable the average of

the total number of citations received within two years for the patents produced by each country, referred to as “average citations”.

3.2. Regression Results. We next develop a panel regression model with fixed effects to compare the patent quality of non-US inventors to that of US inventors over the period of 1980-2011. Our model is given by

$$(3.1) \quad Y_{cst} = \alpha_0 + \sum_{i=1}^{36} \alpha_i s_i + \sum_{i=1}^{29} \beta_i t_i + \eta'_1 X_{cst,80} + \eta'_2 X_{cst,90} + \eta'_3 X_{cst,00} + \varepsilon_{cst},$$

where Y_{cst} is either the citation frequency, or the average number of citations, received in 2 years for country c , sector s and grant year t ,¹⁵ $\{s_i\}$ are 36 sector (sub-category) dummies,¹⁶ $\{t_i\}$ are 29 grant year dummies,¹⁷ and ε_{cst} is the regression error term. In addition, the following regressors are included to obtain difference-in-differences (DiD) estimates (vis-à-vis the US):

$$X_{cst,80} = (\mathbf{1}\{c = \text{JP}, 1980 \leq t \leq 1989\}, \dots, \mathbf{1}\{c = \text{RW}, 1980 \leq t \leq 1989\})',$$

$$X_{cst,90} = (\mathbf{1}\{c = \text{JP}, 1990 \leq t \leq 1999\}, \dots, \mathbf{1}\{c = \text{RW}, 1990 \leq t \leq 1999\})',$$

$$X_{cst,00} = (\mathbf{1}\{c = \text{JP}, 2000 \leq t \leq 2009\}, \dots, \mathbf{1}\{c = \text{RW}, 2000 \leq t \leq 2009\})',$$

where $\mathbf{1}\{\cdot\}$ is the usual indicator function.¹⁸

The parameters of interest are the coefficients η_1 , η_2 and η_3 , which capture the difference compared to the US in the 1980s, 1990s and 2000s, respectively, for each country.¹⁹ To account for the different sample sizes of cohorts, we adopt weighted regression with the

¹⁵There are all 16 countries (or groups of countries) including RW (rest of the world), 37 sectors (sub-categories) and 30 grant years (excluding the last couple of years so that patents for each grant year have a two-year-period of citations received).

¹⁶Sub-category is a variable from the NBER datasets and it sub-categorizes the six industrial categories. There are 37 sub-categories in total.

¹⁷While the dataset covers all 32 years from 1980 to 2011, our regression here considers patents up to only 2009 to allow for full 2-year forward citations; also, year 1980 is omitted.

¹⁸We have also conducted DiD estimation across different time intervals (periods of 8, 9, 11 and 12 years) but the results are qualitatively unaffected.

¹⁹The size of the coefficient matrix is (15×1) instead of (16×1) since we omit the US benchmark case.

weights given by the number of patents in each cell. Standard errors are clustered by country and sub-category.

Table 2 reports the estimation results which report the sector-adjusted and grant-year-adjusted cross-country trends in patent quality represented by two different citation measures. Indeed, we find that these results are consistent with the earlier observations in Figure 1, whether we take citation frequency or average citations as the dependent variable. We summarize our findings as follows.

Fact 1. *Patent quality of the emerging Asian economies of Korea and Taiwan caught up with the US during the 1990s, while similar catch-up occurred for China during the 2000s.*

Patent quality of Korea and Taiwan both lagged substantially behind that of the US in the 1980s: in terms of citation frequency, the coefficient value of the DiD regressor was -0.087 for Korea and -0.058 for Taiwan (both significant at 0.1% level), while the corresponding figures on average citations are -0.236 and -0.122, respectively. In the 1990s, however, this deficit in citation frequency was almost halved for Korea (-0.045), while Taiwan achieved statistical parity with the US (in fact, a positive coefficient value, 0.011, though insignificant). This rapid catch-up was also apparent in average citations. Although these countries' relative growth in patent quality faded away in the 2000s, notice that the corresponding coefficient values are still closer to parity with the benchmark than those of the advanced European nations.

For China, similar surge was observed during the 2000s. On both measures, China's patent quality gap against the US became statistically insignificant in this decade. Our findings are consistent with evidence reported by Griffith and Miller (2011), who showed that the proportion of EPO patent applications with at least one Chinese inventor that are near science—more fundamental research and hence, presumably higher quality—was higher than that of all EPO patent application for the period of 1995-2005.²⁰

²⁰Griffith and Miller (2011) attributed part of the success of China to investment of foreign multinationals. See also Hu and Jefferson (2009) for explanations behind China's patent surge.

TABLE 2. Regression Results (citation frequency and average citations)

Country	Dependent variable:					
	Citation Frequency			Average Citations		
	(1)	(2)	(3)	(4)	(5)	(6)
	1980-1989	1990-1999	2000-2009	1980-1989	1990-1999	2000-2009
Japan (JP)	.052*** (.010)	-.006 (.010)	-.038*** (.011)	.122*** (.032)	-.078 (.046)	-.184*** (.040)
Germany (DE)	-.026* (.010)	-.079*** (.009)	-.097*** (.011)	-.059* (.026)	-.241*** (.038)	-.291*** (.036)
EU	-.048*** (.011)	-.086*** (.010)	-.088*** (.010)	-.105*** (.027)	-.244*** (.041)	-.251*** (.028)
France (FR)	-.048*** (.010)	-.096*** (.010)	-.109*** (.009)	-.113*** (.029)	-.275*** (.040)	-.317*** (.032)
Great Britain (GB)	-.024 (.013)	-.066*** (.010)	-.060*** (.008)	-.055 (.034)	-.201*** (.040)	-.193*** (.024)
Taiwan (TW)	-.058*** (.012)	.011 (.023)	-.039* (.020)	-.122*** (.031)	.083 (.114)	-.143* (.057)
Korea (KR)	-.087*** (.023)	-.045* (.019)	-.064*** (.012)	-.236*** (.038)	-.166* (.070)	-.243*** (.043)
Canada (CA)	-.039*** (.010)	-.040*** (.011)	-.030** (.009)	-.087*** (.025)	-.128* (.050)	-.108*** (.027)
Switzerland (CH)	-.022 (.013)	-.079*** (.011)	-.096*** (.009)	-.040 (.035)	-.231*** (.039)	-.290*** (.028)
Australia (AU)	-.078*** (.013)	-.088*** (.015)	-.044*** (.011)	-.158*** (.028)	-.251*** (.045)	-.109* (.045)
Israel (IL)	-.034* (.016)	-.050** (.015)	-.033** (.010)	-.059 (.037)	-.110 (.071)	-.102*** (.027)
China (CN)	-.133*** (.039)	-.115*** (.017)	-.005 (.031)	-.227** (.085)	-.360*** (.049)	-.062 (.075)
India (IN)	-.112** (.036)	-.118*** (.022)	-.084*** (.012)	-.170* (.074)	-.308*** (.060)	-.254*** (.034)
Former Soviet Union (FSU)	-.136*** (.014)	-.150*** (.015)	-.081*** (.015)	-.251*** (.033)	-.353*** (.049)	-.250*** (.035)
Rest of the World (RW)	-.100*** (.011)	-.098*** (.011)	-.065*** (.011)	-.184*** (.027)	-.245*** (.046)	-.186*** (.033)

Notes: Columns (1)-(3) show estimated coefficient values for the three DiD regressors with citation frequency as dependent variable, and columns (4)-(6) contain corresponding estimates for average citations.

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

1. In the parentheses are standard errors.

2. In each regression, grant year dummies and sub-category dummies are also included as regressors.

3. We use standard errors clustered by country and sub-category.

4. We use weighted regression where the sample size of each cohort is used as the weight.

Fact 2. *Patent quality of the advanced economies of Europe and Japan declined relative to the US.*

The second notable stylized fact is the relative decline of the advanced nations of Europe and Japan. In the initial sample decade of 1980s, EU and the major European countries (Germany, France, Great Britain and Switzerland) had relatively small patent quality deficits against the US in terms of both citation frequency and average citations. For instance, in terms of citation frequency, the coefficient value was -0.026 for Germany and -0.024 for Great Britain, with the latter being statistically insignificant. Japanese patent quality in the 1980s was actually better, with the corresponding coefficient being 0.052. However, significant decline occurred during the 1990s for all these countries. For Germany, the citation frequency coefficient dropped to -0.079, and for Great Britain, it became -0.066 (significant at 0.1% level). For Japan, the decline erased its advantage altogether. The last decade witnessed continued decline for these countries, albeit at somewhat slower pace, except for Great Britain who reduced the deficit slightly.

Fact 3. *The US maintained highest patent quality.*

Perhaps the most noteworthy observation from our analysis here is the confirmation of the dominance of US patent quality. In the 1980s, although the US displayed better patent quality against most countries, the advantage was relatively small against other advanced nations; also, Japan had higher patent quality while the difference from Great Britain or Switzerland was statistically insignificant. In the 1990s, however, the relative position of the US strengthened substantially against all countries on both measures, except for the case of Korea and Taiwan. The final decade saw this trend continuing for many countries, especially, Japan and most European countries. Other countries that managed to reverse the trends did so in relatively small scale. Korea and Taiwan went from the rapid catching-up in the previous decade to deficits. China was the only country that achieved statistical parity with the US in the 2000s.

The remaining countries did not reveal patterns that were as conclusive as the aforementioned countries. Their estimation results depended on the dependent variable, except during the 2000s when they all recorded some gains relative to 1990s in terms of both measures of patent quality. Among them, it is worth noticing that, despite a substantial increase in the volume of patents since 1980, India's patent quality has not displayed similar tangential improvement.

The main regression results here are intact if we control for aggregate sectors (six industrial categories as defined by the NBER data) instead of using sub-category sectors and also if we use a five-year window to compute the citation frequency and average citations instead of using the two-year window. See Tables C.1 and C.2 in Appendix C.

3.3. Hirsch Index. While citation frequencies and average citations both capture some aspect of a country's patent quality, such measures may not explain overall technological innovation because they fail to take into account the total size or productivity of the innovation sector, i.e. the number of patents granted. One measure to capture citation-adjusted total research output is the Hirsch index, or simply H-index, which is widely used to measure a scholar's research performance.²¹

In Appendix B, we report two sets of estimation results (Poisson and negative binomial models) with H-indices as dependent variables. These results broadly support our previous findings on average patent quality. With the quantity of patents also taken into account, we see that Korea and Taiwan actually continued to strengthen their worldwide positions during the 2000s; moreover, substantial technological gaps still separate the emerging economies from the advanced economies of Japan and Europe. In order to highlight these overall trends, in Table 3, we present the international rankings based on H-index regression

²¹An author with a total of n papers has H-index h if he or she has more than h papers that have been cited at least h times and the other $n - h$ papers have been cited at most h times. This measure is originally proposed by Hirsch (2005) to analyze individuals' research output in physics. In economics, Ellison (2013) recently used Hirsch-like indices to examine how well different indices explain labor market outcomes for young, tenured economists at 50 US departments.

TABLE 3. Hirsch Index rankings

Country	Hirsch-index rankings		
	1980-1989	1990-1999	2000-2009
Japan (JP)	1	1	1
Germany (DE)	2	2	2
EU	3	3	3
France (FR)	5	6	8
Great Britain (GB)	4	4	5
Taiwan (TW)	10	7	6
Korea (KR)	13	9	7
Canada (CA)	6	5	4
Switzerland (CH)	7	8	12
Australia (AU)	9	12	11
Israel (IL)	11	11	10
China (CN)	14	14	13
India (IN)	15	15	15
Former Soviet Union (FSU)	12	13	14
Rest of the world (RW)	8	10	9

Notes: These ranks are based on our regression model with the Hirsch index of each location as the dependent variable. We rank each country in descending order according to its coefficient estimate for each decade.

results for each of the three previous decades. A higher ranking means an H-index closer to that of the US in the corresponding decade. We observe that Japan, Germany and EU maintained the top 3 positions throughout the three decades. The rankings of Korea and Taiwan rose most substantially, while France and Switzerland showed notable declines.

4. MEASURING DISTANCE TO THE KNOWLEDGE FRONTIER

The patent citations data enable us to explore another channel of measuring the trends in technological progress. Taking US as the knowledge frontier, we next consider the speed with which US patents are cited by non-US patents. As discussed in Introduction, our perspective is that an inventor who is quicker at citing a frontier patent is closer to the frontier itself.

4.1. First Look. Let us begin by documenting how much longer on average it takes for inventors of a given country to make first citations to US patents than US inventors. Reduced citation lags may result from multiple sources other than improvement in technology capacity of the citing inventors. Since higher quality patents may be more likely to be cited, advance in US patent quality could lead to quicker citations by other inventors; another potential reason for smaller citation lags would be diminished international frictions against knowledge spillover due to, for example, better communication technology. In order to take account of this issue, we consider the relative distance to the US benchmark across countries. The sample period is divided into 8 equal-length sub-periods to scrutinize the trends.

The graphs of Figure 2 demonstrate several noteworthy features of the cross-country trends in average time to first citation. First, there were no significant differences for the advanced European nations (including Switzerland) and Japan in the early 80s relative to the US, and this remained true throughout the entire sample period. Second, for the remaining nations, substantial lags existed in the early 80s but these lags decreased throughout the sample period. In particular, the rate of reduction was most marked for Korea, Taiwan and China, the three countries who also made dramatic catch-up in patent quality as seen in Section 3 above. For instance, between 1980-83, the average time it took a Korean inventor to cite a US patent was more than 150% that for her US counterpart; by 1996-1999, the deficit was actually reversed. For China, parity with US inventors came about during the latter part of 2000s.

4.2. Econometric Model. In this section, we formally estimate distance to the knowledge frontier by defining the latter as the set of patents taken out by inventors residing in the US. To achieve our goal, we use the fixed-effects estimator of Griffith, Lee, and Van Reenen (2011). We first provide a brief review of their estimator and then present our empirical results.

FIGURE 2. Time to first citation

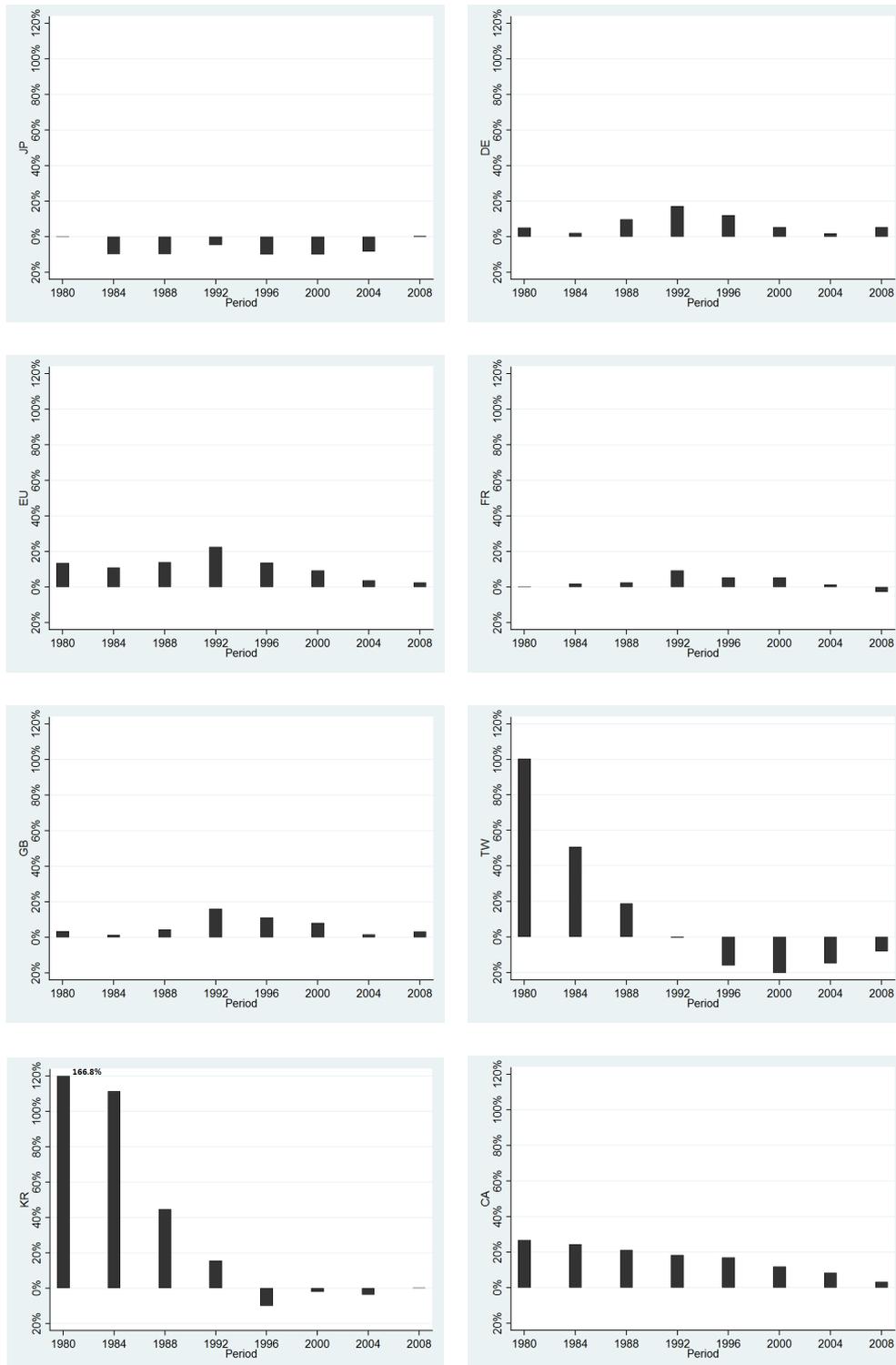
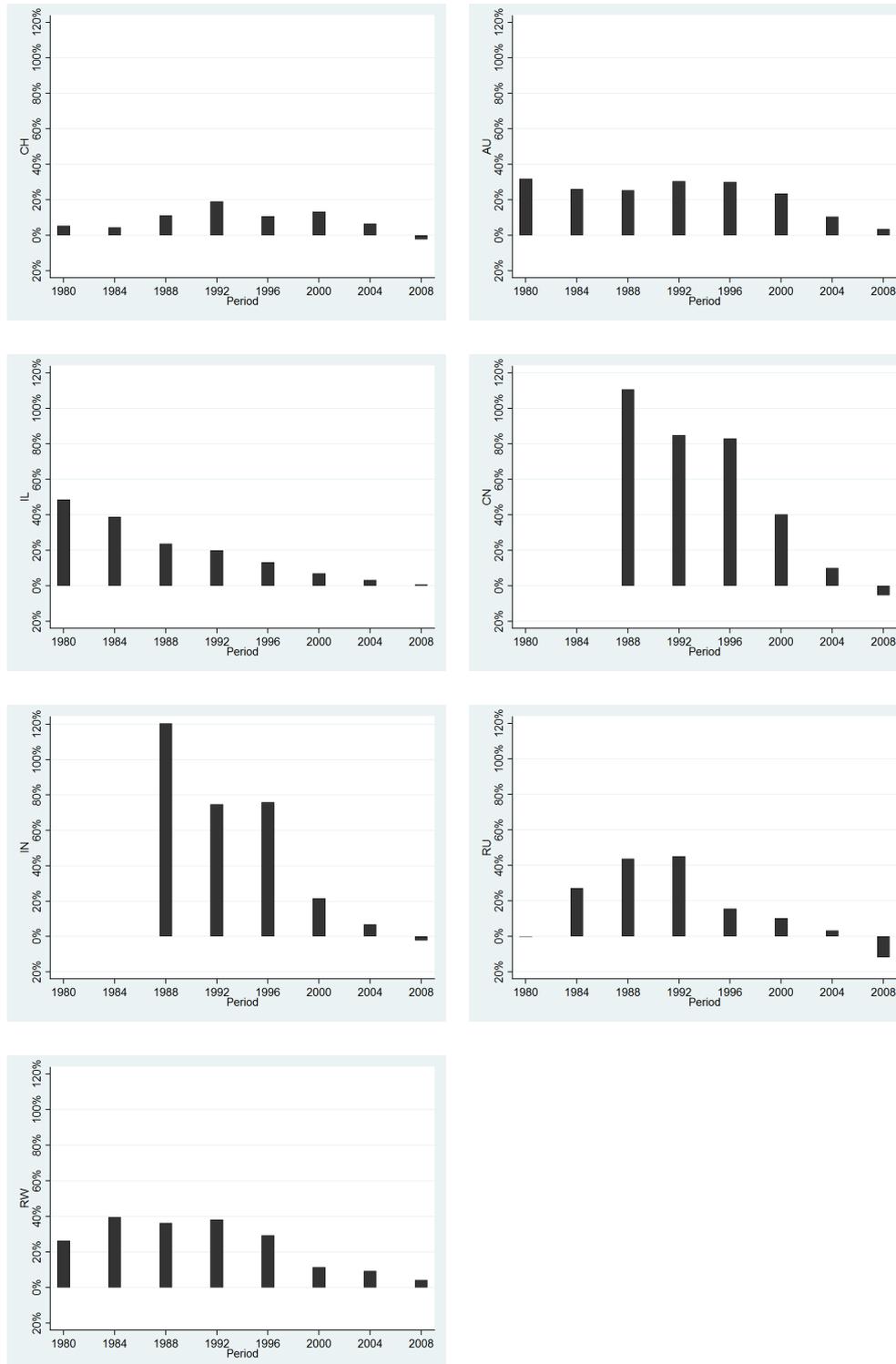


FIGURE 2. Time to first citation (continued)



Notes: Each graph shows the relative time that it takes for an inventor of the given country to cite a US patent for the first time. For example, in the graph for Korea, 166.8% for the first sub-period indicates that it took 166.8% longer (in mean number of days) when the first citation of a US patent was made by a Korean inventor than when the first citation was made by a US inventor.

In the framework of Griffith, Lee, and Van Reenen (2011), there are a set of inventions $i = 1, \dots, I$ and a set of inventors $j = 1, \dots, J$. The inventors will learn of invention i after a time period T_{ij} and therefore, T_{ij} can be thought of as the “citation (or diffusion) lag” between invention i and inventor j . There are several factors which determine the citation lag including characteristics of the invention i , Z_i , characteristics of the inventor j , Z_j and the joint characteristics of the invention-inventor match, Z_{ij} . There will be a set of non-geographical variables as well as geographical variables that will influence the speed at which technology spillover occurs.

The hazard function of the citation lag is affected by a vector of explanatory variables X_{ij} , incorporating the empirically observable counterparts to Z_{ij} and Z_j and an unobservable fixed effect, U_i , which absorbs all the factors specific to the cited patent, Z_i . Unobserved heterogeneity U_i includes patent quality among other things.

In this section, we regard the set of US patents as the frontier and aim to estimate the distance to the frontier by regressing US (cited) patents on characteristics of citing patents from non-US inventors. Since higher quality patents are likely to be cited more quickly, it is crucial to control for unobserved patent quality, as emphasized by Griffith, Lee, and Van Reenen (2011).²² As a consequence, our estimates would be robust even if there had been changing trends in the quality of US patents over time.

Specifically, Griffith, Lee, and Van Reenen (2011) consider a multiple-spell version of the mixed proportional hazards model. Their regression model can be written as

$$(4.1) \quad \log \Lambda_i(T_{ij}) = -X'_{ij}\beta - U_i + \varepsilon_{ij},$$

where β is a vector of unknown parameters, $\lambda_i(\cdot)$ is a cited-patent specific baseline hazard function, $\Lambda_i(t) = \int_0^t \lambda_i(u)du$, ε_{ij} is i.i.d. over i and j , independent of X_{ij} , and ε_{ij} has the cumulative distribution function $F(\varepsilon_{ij}) = 1 - \exp[-\exp(\varepsilon_{ij})]$.²³ Then an estimate of β can

²²To this end, we only use “within-cited-patent” variations.

²³Griffith, Lee, and Van Reenen (2011) allow for not only the unobserved fixed effect U_i but also the cited-patent specific baseline hazard function $\lambda_i(\cdot)$.

be obtained using a conditional likelihood approach, while accounting for right censoring. The covariates of interest are inventor country dummies for citing patents. We interpret their coefficients as the corresponding countries' distance to the knowledge frontier. A negative (positive) value means that the country is behind (ahead of) the frontier.

4.3. Regression Results. In our empirical analysis, we fix the “potentially cited” country to be the US and consider only US patents. As discussed in the previous subsection, this amounts to interpreting the US as the knowledge frontier. This simplifying assumption is a reasonable first-order approximation in view of our findings in Section 3. We split the sample period into 8 sub-periods of each lasting four years and estimate for each sub-period the citation lag model with the first two citations ($J = 2$), as described in the previous subsection.

Included covariates for citing patents are the self citation indicator (whether a citation is from the identical assignee), the same sub-category dummy (whether a citation is from the same sub-category), the base cohort size (which is the number of patents in the citing country and technology sub-category for the citing year), the corporation dummy (whether the citing first assignee is a corporation or not), category dummies (six industry level dummies), and citing country dummies. Among these, the citing country dummies are covariates of interest. Their estimated coefficients represent how fast the non-US inventors cite US patents compared to US inventors, and hence, how close the non-US inventors are to the technology frontier.

Table 4 shows the estimation results.²⁴ For example, the first row of Table 4 displays the coefficient estimates for Japan through the 8 sub-periods. The estimate for the first sub-period in this row is -0.21 which means that inventors in Japan cited US patents about 21% slower than US inventors.

²⁴We include China and India as part of the rest of the world for the first two periods to avoid imprecisely estimated estimators due to the small sample sizes of such cohorts.

TABLE 4. Main estimation results of the citation lag model

Country	Period							
	1 (1980- 1983)	2 (1984- 1987)	3 (1988- 1991)	4 (1992- 1995)	5 (1996- 1999)	6 (2000- 2003)	7 (2004- 2007)	8 (2008- 2011)
Japan (JP)	-0.21 (0.02)	-0.13 (0.02)	-0.12 (0.02)	-0.23 (0.02)	0.03 (0.02)	0.03 (0.02)	-0.11 (0.03)	-0.01 (0.06)
Germany (DE)	-0.29 (0.03)	-0.25 (0.03)	-0.11 (0.03)	-0.24 (0.03)	-0.01 (0.03)	0 (0.03)	-0.12 (0.04)	-0.28 (0.1)
EU	-0.26 (0.03)	-0.2 (0.03)	-0.2 (0.03)	-0.31 (0.03)	-0.05 (0.03)	-0.05 (0.03)	-0.22 (0.04)	-0.13 (0.1)
France (FR)	-0.22 (0.02)	-0.08 (0.02)	0.01 (0.01)	-0.03 (0.01)	0.13 (0.01)	0.11 (0.01)	0.06 (0.02)	0.07 (0.05)
Great Britain (GB)	-0.41 (0.03)	-0.3 (0.03)	-0.26 (0.02)	-0.32 (0.02)	-0.03 (0.02)	-0.08 (0.02)	-0.15 (0.03)	-0.19 (0.09)
Taiwan (TW)	-1.23 (0.11)	-1.04 (0.09)	-0.5 (0.06)	-0.35 (0.04)	0.09 (0.03)	-0.03 (0.03)	-0.11 (0.03)	-0.02 (0.07)
Korea (KR)	-0.9 (0.08)	-0.67 (0.05)	-0.33 (0.04)	-0.22 (0.03)	0.13 (0.02)	0.19 (0.02)	0.06 (0.03)	0.09 (0.08)
Canada (CA)	-0.48 (0.06)	-0.33 (0.06)	-0.69 (0.16)	-0.9 (0.14)	-0.5 (0.11)	-0.48 (0.07)	-0.52 (0.06)	-0.11 (0.1)
Switzerland (CH)	-0.44 (0.03)	-0.37 (0.03)	-0.37 (0.06)	-0.43 (0.06)	-0.1 (0.05)	-0.28 (0.05)	-0.4 (0.09)	-0.18 (0.2)
Australia (AU)	-0.22 (0.04)	-0.17 (0.05)	-0.34 (0.03)	-0.36 (0.02)	-0.08 (0.02)	-0.11 (0.02)	-0.35 (0.03)	-0.22 (0.07)
Israel (IL)	-0.7 (0.09)	-0.61 (0.07)	-0.12 (0.05)	-0.31 (0.05)	0.07 (0.05)	-0.08 (0.05)	-0.13 (0.07)	0.27 (0.16)
China (CN)			-0.37 (0.06)	-0.41 (0.05)	-0.24 (0.04)	-0.17 (0.04)	-0.44 (0.05)	-0.31 (0.11)
India (IN)			-0.79 (0.21)	-0.63 (0.17)	-0.28 (0.11)	-0.4 (0.08)	-0.44 (0.09)	-0.11 (0.12)
Former Soviet Union (FSU)	-0.13 (0.12)	-0.64 (0.14)	-0.34 (0.13)	-0.33 (0.11)	-0.09 (0.1)	-0.22 (0.09)	-0.38 (0.13)	-0.19 (0.31)
Rest of the world (RW)	-0.57 (0.05)	-0.51 (0.05)	-0.44 (0.05)	-0.54 (0.04)	-0.2 (0.04)	-0.15 (0.03)	-0.33 (0.04)	-0.22 (0.1)

Notes: The reported numbers are the estimated coefficient values for the country dummy estimated from the regression results above.

1. In the parentheses are standard errors.

2. Our regression model controls for base cohort size (the number of patents in the citing country and technology sub-category for the citing year), self citations (citations between patents with identical assignees) and within-sub-category citations (citations between patents within the same category). Corporation dummies (whether or not the first assignee is a corporation) and category dummies are also included.

3. We include CN and IN in RW for the first two periods to avoid diverging estimators due to the small sample sizes of such cohorts.

To assist exposition, Figure 3 displays the coefficients of each country dummy together with the corresponding coefficients for the Japanese dummy. In terms of distance to the frontier, Japan is one of the countries that has maintained its proximity to the US throughout the sample period.

Let us summarize our main finding for this section below.

Fact 4. *Most significant gains in narrowing of the distance to the knowledge frontier were made by the emerging economies of Korea, Taiwan and Israel.*

Korea, Taiwan and Israel all began the sample period with citation lag substantially below that of Japan; for instance, during 1980-83, Taiwanese inventors cited US patents about 120% slower than US inventors, which amounted to 100% lag relative to Japan. By 1996-1999, however, all three countries caught up with Japan, and in the case of Korea and Israel, the deficits reversed during the 2000s. Although improved communication technology may have led to general decline in citation lag (i.e. “death of distance” as identified in Griffith, Lee, and Van Reenen (2011)), the asymmetric progress made by this league of countries points to real closing of the distance to the knowledge frontier.

China does not feature in this league. Recall that China actually seemed to achieve rapid progress when we simply considered the average time to first citation of US patent (Figure 2). However, this observation did not survive a rigorous econometric analysis that used multiple citations to estimate the hazard function. Although China closed her distance to the frontier somewhat during the 1990s, the distance grew again in the last decade.

It is also interesting to observe that, in terms of citation speed, the advanced economies of Japan and Europe (as well as Canada, Australia and FSU) actually maintained their relatively close position to the US frontier throughout the sample periods. Japan, in particular, have been more or less on level terms with the US for the last three decades, ahead of all the other countries. Canadian inventors are slower than Japanese inventors despite its geographic proximity to the US.

FIGURE 3. Graphical representation of estimation results in Table 4

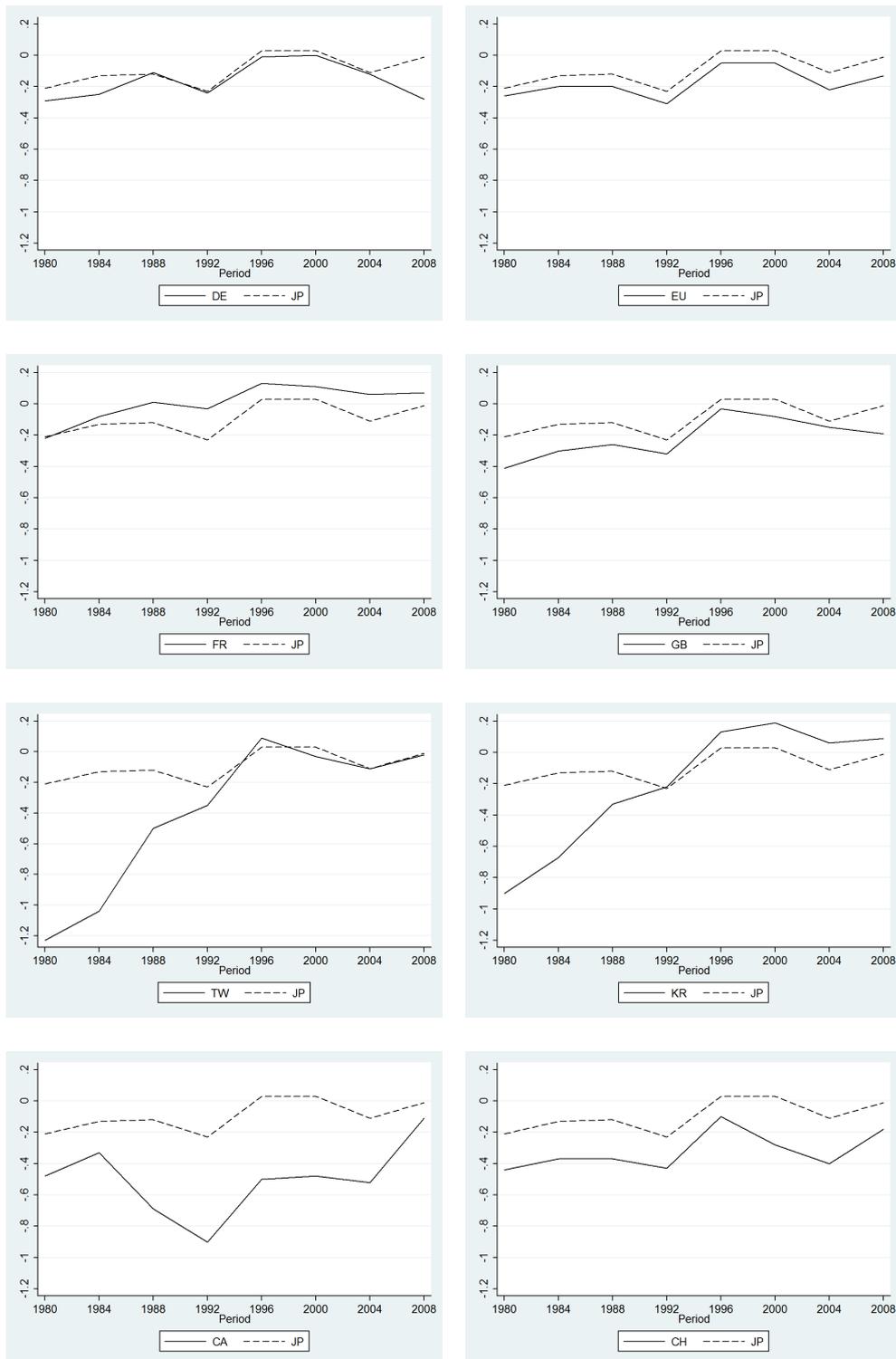
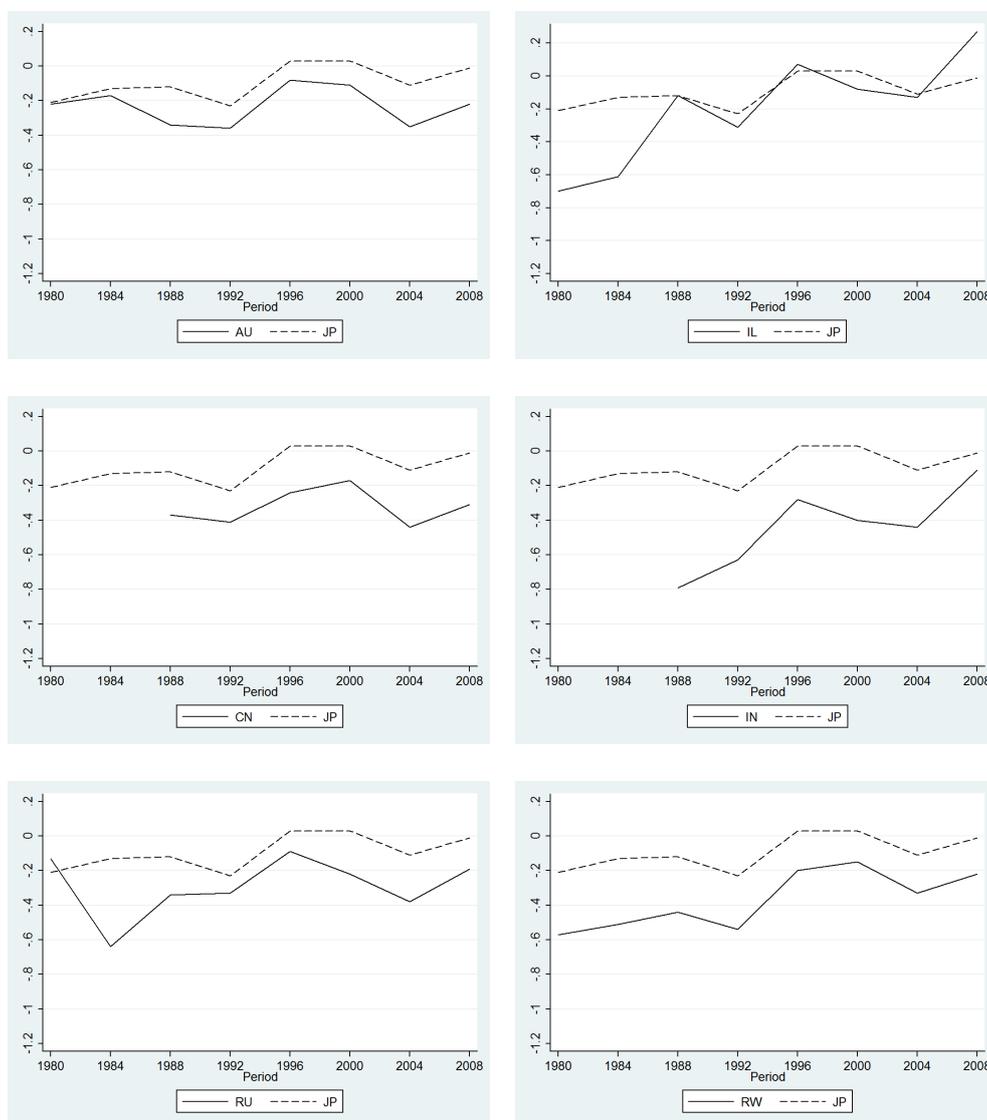


FIGURE 3. Graphical representation of estimation results in Table 4 (continued)



Notes: Each graph plots the coefficient values for the country dummy. Japan is included in every graph as a benchmark.

Our findings are related to the literature on “absorptive capacity”. Griffith, Redding, and Van Reenen (2003, 2004) found evidence that R&D is statistically and economically important in enhancing technology transfer as well as stimulating innovation directly. Mancusi

(2008) investigated the issue of international knowledge spillovers and absorptive capacity. Using EPO patent applications and their citations from 1978 to 2003, Mancusi (2008) concluded that absorptive capacity increases the elasticity of a catching-up country's innovation to international spillovers, but not that of an advanced country. Our estimation results are consistent with this perspective. In particular, unlike Korea, Taiwan and Israel, other emerging countries such as China might not have accumulated a sufficient level of absorptive capacity to benefit from international knowledge spillovers.

One might suspect that our results might be driven by a small number of industry sectors since the economies of Korea and Taiwan, in particular, are highly concentrated (e.g. electronics and computers). In order to address this issue, we also conduct the citation lag model regression sector-wise and report its results in Appendix C (Tables C.3 to C.8). The magnitudes of the coefficients of interest turn out to differ across industries; for instance, the coefficients for Taiwan and Korea in the first sub-period are -1.12 and -0.48 , respectively, for the chemical sector, while the corresponding numbers for the computers and communication sector are -2.65 and -2.2 , respectively. However, in terms of the trends, these sector-wise regression results are qualitatively similar to those of Table 4. In particular, we observe rapid upward trends for Korea, Taiwan and Israel in all six sectors.

5. CONCLUSION

In this paper, we have analyzed cross-country trends in technological progress over the period of 1980-2011 by considering an updated USPTO citations dataset. Our estimation results reveal several noteworthy stylized facts. As widely expected, the emerging Asian economies of Korea, Taiwan and China have indeed achieved rapid inroads towards the technology frontier. In the case of Korea and Taiwan, progress has been made in terms of patent quality as well as distance to the frontier. Chinese patents are on average of substantially higher quality now than before but Chinese inventors have yet to reduce the citation lag relative to the frontier. In contrast, advanced economies of Europe and Japan

have been in steady decline in their patent quality. Perhaps most interestingly, the US has maintained, and in some cases reinforced, its position as the world technology frontier.

Our results pose a number of intriguing questions for the years ahead. On the one hand, the emerging Asian countries would overtake the traditional knowledge powerhouses of Europe and Japan if they could sustain the recent levels of faster technological progress. On the other hand, it will be interesting to see whether these emerging countries will close the gap further against the US. Although Korea and Taiwan managed to elevate the quality of their patents to the US level in the 1990s, US actually pushed ahead in the 2000s. The Korean and Taiwanese experience was repeated by China in the 2000s. Would the US demonstrate another bout of technological resilience in the current decade against China? Last but not least, we also wait to see if other countries newly spring to join the growth path of the aforementioned Asian economies in innovation.

In this study, we focused on patent citations data from the USPTO. While this may have caused some bias in favor of US patents, the trends of all other countries were measured relative to those of the US. Nonetheless, it will be worthwhile also to study the corresponding trends using data from other major patent offices, especially, from the EU. Perhaps the more important future research set out by the current study would be to investigate the sources of technological progress that can help explain the reported cross-country variations. Meaningful insights could be obtained by linking the patent citations data with data on potentially important contributors of knowledge growth, such as R&D expenditures as well as levels and quality of higher education.

APPENDIX A. DATA

We extended the NBER data file, PAT63_99, to include 12 additional years up to December 31, 2011.²⁵ Our data file is named PAT63_11, and it mainly builds on Brownyn Hall's data file, PAT63_02. While the NBER Patent Data Project provides a dataset that includes patents granted up to 2006 (PAT76_06), this does not contain the inventor location of each patent.²⁶ Our data file is constructed from Google's USPTO Bulk Download service that makes publicly available in XML format bibliographic data of all patents granted since 1976 to present.²⁷ We used Python to parse the XML files and extracted the necessary data for our analysis. Tag names for pre-2006 patents that are in codes were deciphered for accurate extraction using USPTO's codebook.

We extracted the following information for each patent: patent number, grant date, three-digit main classification, assignee, assignee code, inventor country, and patents that the given patent cited. See Hall, Jaffe, and Trajtenberg (2001) for details of each variable. Using such raw data, we constructed "subcat" variables, following Hall, Jaffe, and Trajtenberg (2001). The three-digit classification code was matched with each subcat code as provided in the NBER webpage. There were also some new classification codes in the recent years that do not have corresponding subcat codes. For these, we used the match applied in PAT76_06 when possible, and for those that had no matches we just left the subcat variable as missing. The number of patents with missing subcat, which appear only after 2000, does not exceed 80 for each year.

The patent counts did not match with the USPTO statistics for China and Hong Kong. This was mainly due to inconsistent reports of the patent claimers. For example, while the USPTO maintains separate accounts for China and Hong Kong, some Hong Kong inventors reported their country as China. We identified the same problem in PAT63_02 for patents

²⁵The last grant date in the dataset is December 27, 2011 since USPTO grants patents on a weekly basis.

²⁶See <https://sites.google.com/site/patentdatapoint/>.

²⁷See <https://www.google.com/googlebooks/uspto.html>.

granted later than 2000. Also, there were some inventors from Taiwan and Singapore who reported their location as China. In order to rectify this problem, we extracted an extra variable, inventor city, and manually cleaned up the discrepancies. After this clean-up process, the patent counts by country and grant year became consistent with the USPTO statistics.

APPENDIX B. HIRSCH INDEX FOR PATENT CITATIONS

Table B.1 reports the H-index of each country for the 8 sub-periods within 1980-2011. The US strictly dominates all other countries in all periods; the growing trends of the developing countries such as China, India, Korea and Taiwan are also evident.

TABLE B.1. Hirsch Index

Country	Period							
	1 (1980- 1983)	2 (1984- 1987)	3 (1988- 1991)	4 (1992- 1995)	5 (1996- 1999)	6 (2000- 2003)	7 (2004- 2007)	8 (2008- 2011)
United States (US)	193	233	277	317	336	268	150	56
Japan (JP)	99	117	137	148	168	126	72	26
Germany (DE)	76	88	95	106	99	88	54	20
EU	73	88	90	102	118	103	60	22
France (FR)	70	74	89	95	95	79	44	18
Great Britain (GB)	70	81	101	103	108	94	60	19
Taiwan (TW)	12	21	35	63	75	78	51	21
Korea (KR)	19	33	47	64	76	77	52	15
Canada (CA)	62	77	87	108	111	96	52	19
Switzerland (CH)	58	58	62	71	67	51	33	11
Australia (AU)	36	42	49	65	60	69	38	24
Israel (IL)	34	39	53	73	87	89	51	20
China (CN)	5	11	27	20	21	24	26	14
India (IN)	8	10	11	19	22	27	25	10
Former Soviet Union (FSU)	30	32	28	33	39	33	20	7
Rest of the world (RW)	45	51	53	64	81	70	44	15

Notes: The sample period is divided into 8 equal-length sub-periods and we consider each country of each sub-period as an “author” to calculate the H-index for each “author.” An author with a total of n papers has H-index h if he has more than h papers that have been cited at least h times and the other $n - h$ papers have been cited at most h times.

We run Poisson regression and negative binomial regression with the H-indices as the dependent variable to examine the trends observed in Table B.1. We use the following model specification:

$$Y_{cst} = \exp \left(\alpha_0 + \sum_{i=1}^{36} \alpha_i s_i + \sum_{i=1}^{29} \beta_i t_i + \eta'_1 X_{cst,80} + \eta'_2 X_{cst,90} + \eta'_3 X_{cst,00} \right) + \varepsilon_{cst},$$

where the variables on the right-hand side are defined as in (3.1).²⁸

Here, the dependent variable, Y_{cst} , is the H-index for a given country c , sector s and year t . For example, if $y_{JP,11,1980} = h$, this means that considering the patents granted in 1980 for subsection category 11 by Japanese inventors as patents of one big inventor, her H-index is h . Since this dependent variable is count data, we apply Poisson regression and negative binomial regression to estimate the coefficients. The standard errors are again clustered by country and sub-category.

The results are shown in Table B.2. These results are broadly consistent with our findings on citation frequency and average citations. The main regression results remain unaffected if we control for aggregate sectors instead of using sub-category sectors. See Table B.3.

²⁸As in (3.1), there are 36 sub-category dummies and 29 year dummies.

TABLE B.2. Regression Results for Hirsch Index

Country	Method:					
	Poisson regression			Negative binomial regression		
	(1)	(2)	(3)	(4)	(5)	(6)
	1980-1989	1990-1999	2000-2009	1980-1989	1990-1999	2000-2009
Japan (JP)	-0.596*** (.040)	-0.673*** (.054)	-0.763*** (.078)	-0.601*** (.040)	-0.670*** (.057)	-0.752*** (.082)
Germany (DE)	-0.952*** (.050)	-1.214*** (.052)	-1.234*** (.059)	-0.947*** (.048)	-1.198*** (.052)	-1.214*** (.063)
EU	-1.158*** (.049)	-1.321*** (.048)	-1.256*** (.063)	-1.158*** (.046)	-1.319*** (.046)	-1.246*** (.065)
France (FR)	-1.304*** (.043)	-1.488*** (.041)	-1.591*** (.062)	-1.308*** (.042)	-1.478*** (.041)	-1.573*** (.067)
Great Britain (GB)	-1.210*** (.045)	-1.433*** (.047)	-1.402*** (.066)	-1.215*** (.043)	-1.431*** (.048)	-1.389*** (.070)
Taiwan (TW)	-2.506*** (.108)	-1.827*** (.091)	-1.528*** (.105)	-2.519*** (.105)	-1.820*** (.090)	-1.505*** (.104)
Korea (KR)	-3.167*** (.071)	-2.047*** (.097)	-1.556*** (.101)	-3.186*** (.071)	-2.054*** (.095)	-1.538*** (.103)
Canada (CA)	-1.479*** (.064)	-1.468*** (.052)	-1.352*** (.070)	-1.486*** (.061)	-1.465*** (.050)	-1.341*** (.071)
Switzerland (CH)	-1.677*** (.074)	-1.973*** (.070)	-2.023*** (.067)	-1.676*** (.072)	-1.960*** (.069)	-2.004*** (.070)
Australia (AU)	-2.259*** (.087)	-2.305*** (.072)	-1.970*** (.097)	-2.269*** (.083)	-2.303*** (.071)	-1.945*** (.104)
Israel (IL)	-2.525*** (.067)	-2.278*** (.076)	-1.831*** (.108)	-2.545*** (.065)	-2.294*** (.074)	-1.831*** (.109)
China (CN)	-3.530*** (.075)	-3.633*** (.084)	-2.609*** (.102)	-3.546*** (.072)	-3.631*** (.080)	-2.575*** (.104)
India (IN)	-3.675*** (.082)	-3.671*** (.126)	-2.855*** (.122)	-3.694*** (.083)	-3.665*** (.124)	-2.823*** (.125)
Former Soviet Union (FSU)	-2.722*** (.078)	-3.116*** (.068)	-2.828*** (.077)	-2.731*** (.076)	-3.111*** (.067)	-2.804*** (.080)
Rest of the world (RW)	-1.986*** (.070)	-2.075*** (.051)	-1.752*** (.070)	-1.992*** (.066)	-2.069*** (.051)	-1.731*** (.074)

Notes: Columns (1)-(3) show estimated coefficient values for the three DiD regressors from Poisson regression, and columns (4)-(6) contain corresponding estimates from negative binomial regression.

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

1. In the parentheses are standard errors.

2. Grant year dummies and sub-category dummies are also included as regressors.

3. We use standard errors clustered by country and sub-category. The main results are not sensitive to the choice of standard errors.

4. For robustness we conduct both Poisson regression and negative binomial regression, which are standard methods in count data analysis.

TABLE B.3. Regression Results for Hirsch Index (with category dummies)

Country	Method:					
	Poisson regression			Negative binomial regression		
	(1)	(2)	(3)	(4)	(5)	(6)
1980-1989	1990-1999	2000-2009	1980-1989	1990-1999	2000-2009	
Japan (JP)	-.596*** (.068)	-.673*** (.083)	-.763*** (.095)	-.603*** (.069)	-.669*** (.084)	-.749*** (.095)
Germany (DE)	-.952*** (.077)	-1.214*** (.085)	-1.234*** (.087)	-.936*** (.074)	-1.186*** (.082)	-1.194*** (.086)
EU	-1.158*** (.078)	-1.321*** (.087)	-1.256*** (.096)	-1.144*** (.077)	-1.305*** (.085)	-1.224*** (.094)
France (FR)	-1.304*** (.075)	-1.488*** (.080)	-1.591*** (.087)	-1.296*** (.073)	-1.467*** (.077)	-1.557*** (.086)
Great Britain (GB)	-1.210*** (.078)	-1.433*** (.085)	-1.402*** (.093)	-1.201*** (.077)	-1.420*** (.083)	-1.372*** (.092)
Taiwan (TW)	-2.452*** (.119)	-1.824*** (.115)	-1.525*** (.122)	-2.453*** (.119)	-1.801*** (.113)	-1.477*** (.120)
Korea (KR)	-3.113*** (.090)	-2.043*** (.119)	-1.556*** (.119)	-3.119*** (.088)	-2.047*** (.117)	-1.517*** (.119)
Canada (CA)	-1.477*** (.095)	-1.468*** (.091)	-1.352*** (.096)	-1.462*** (.092)	-1.447*** (.088)	-1.324*** (.094)
Switzerland (CH)	-1.675*** (.095)	-1.971*** (.097)	-2.019*** (.099)	-1.657*** (.093)	-1.940*** (.095)	-1.973*** (.098)
Australia (AU)	-2.248*** (.113)	-2.298*** (.107)	-1.967*** (.119)	-2.233*** (.112)	-2.277*** (.107)	-1.912*** (.120)
Israel (IL)	-2.506*** (.107)	-2.271*** (.118)	-1.825*** (.135)	-2.508*** (.107)	-2.273*** (.115)	-1.808*** (.133)
China (CN)	-3.431*** (.108)	-3.556*** (.118)	-2.591*** (.123)	-3.432*** (.108)	-3.536*** (.119)	-2.510*** (.127)
India (IN)	-3.585*** (.082)	-3.591*** (.137)	-2.821*** (.136)	-3.583*** (.077)	-3.568*** (.134)	-2.754*** (.138)
Former Soviet Union (FSU)	-2.700*** (.106)	-3.083*** (.101)	-2.798*** (.107)	-2.688*** (.104)	-3.064*** (.101)	-2.744*** (.108)
Rest of the world (RW)	-1.987*** (.099)	-2.074*** (.090)	-1.752*** (.100)	-1.970*** (.095)	-2.050*** (.088)	-1.703*** (.099)

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

1. The specifications are same with Table B.2 except that here we include category dummies instead of sub-category dummies.

APPENDIX C. ROBUSTNESS CHECK

TABLE C.1. Regression Results (citation frequency and average citation, with category dummies)

Country	Dependent variable:					
	Citation Frequency			Average Citation		
	(1)	(2)	(3)	(4)	(5)	(6)
	1980-1989	1990-1999	2000-2009	1980-1989	1990-1999	2000-2009
Japan (JP)	.055*** (.016)	-.003 (.019)	-.036* (.014)	.129** (.045)	-.068 (.064)	-.179*** (.048)
Germany (DE)	-.032* (.015)	-.088*** (.017)	-.104*** (.013)	-.072* (.035)	-.263*** (.054)	-.312*** (.041)
EU	-.053*** (.014)	-.093*** (.018)	-.094*** (.014)	-.118*** (.032)	-.264*** (.057)	-.272*** (.037)
France (FR)	-.053*** (.014)	-.104*** (.017)	-.117*** (.014)	-.124*** (.035)	-.296*** (.055)	-.341*** (.041)
Great Britain (GB)	-.030 (.016)	-.075*** (.017)	-.068*** (.014)	-.069 (.038)	-.224*** (.056)	-.214*** (.040)
Taiwan (TW)	-.055*** (.013)	.019 (.031)	-.032 (.020)	-.123*** (.033)	.106 (.145)	-.120 (.064)
Korea (KR)	-.089*** (.024)	-.038 (.027)	-.057*** (.013)	-.244*** (.041)	-.139 (.101)	-.218*** (.045)
Canada (CA)	-.040** (.013)	-.045** (.017)	-.037* (.014)	-.091** (.030)	-.143* (.063)	-.129** (.039)
Switzerland (CH)	-.036* (.015)	-.094*** (.017)	-.108*** (.013)	-.071 (.037)	-.268*** (.050)	-.325*** (.038)
Australia (AU)	-.076*** (.018)	-.091*** (.024)	-.057*** (.017)	-.156*** (.035)	-.260*** (.064)	-.149** (.046)
Israel (IL)	-.036 (.020)	-.050 (.026)	-.031 (.019)	-.065 (.043)	-.111 (.093)	-.102* (.050)
China (CN)	-.129** (.040)	-.116*** (.024)	-.011 (.032)	-.217* (.086)	-.361*** (.062)	-.085 (.077)
India (IN)	-.132*** (.032)	-.151*** (.034)	-.109*** (.024)	-.212** (.067)	-.377*** (.087)	-.304*** (.039)
Former Soviet Union (FSU)	-.143*** (.020)	-.155*** (.023)	-.085*** (.019)	-.266*** (.041)	-.365*** (.067)	-.259*** (.047)
Rest of the world (RW)	-.105*** (.014)	-.101*** (.019)	-.066*** (.018)	-.193*** (.031)	-.252*** (.061)	-.187** (.058)

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

1. The specifications are the same as for Table 2 except that here we include category dummies instead of sub-category dummies.

TABLE C.2. Regression Results (citation frequency and average citation, with 5-year windows)

Country	Dependent variable:					
	Citation Frequency			Average Citation		
	(1)	(2)	(3)	(4)	(5)	(6)
	1980-1989	1990-1999	2000-2006	1980-1989	1990-1999	2000-2006
Japan (JP)	.042*** (.009)	-.022*** (.007)	-.050*** (.009)	.243 (.153)	-.992*** (.220)	-1.445*** (.221)
Germany (DE)	-.033*** (.010)	-.079*** (.006)	-.118*** (.010)	-.326* (.128)	-1.498*** (.172)	-1.755*** (.189)
EU	-.065*** (.010)	-.092*** (.007)	-.119*** (.014)	-.478*** (.127)	-1.477*** (.185)	-1.545*** (.166)
France (FR)	-.055*** (.009)	-.093*** (.009)	-.122*** (.010)	-.540*** (.149)	-1.603*** (.187)	-1.851*** (.186)
Great Britain (GB)	-.028* (.012)	-.064*** (.007)	-.069*** (.011)	-.270 (.152)	-1.213*** (.174)	-1.103*** (.158)
Taiwan (TW)	-.089*** (.012)	-.041*** (.012)	-.068*** (.016)	-.569*** (.161)	-.769* (.361)	-1.419*** (.245)
Korea (KR)	-.095*** (.027)	-.083*** (.012)	-.081*** (.010)	-.970*** (.183)	-1.773*** (.309)	-1.719*** (.216)
Canada (CA)	-.040*** (.012)	-.026*** (.008)	-.024* (.011)	-.364** (.133)	-.705** (.229)	-.631*** (.168)
Switzerland (CH)	-.039*** (.012)	-.080*** (.010)	-.114*** (.010)	-.259 (.142)	-1.378*** (.178)	-1.699*** (.139)
Australia (AU)	-.085*** (.012)	-.068*** (.010)	-.069*** (.014)	-.617*** (.130)	-1.253*** (.181)	-.979*** (.200)
Israel (IL)	-.022 (.018)	-.034*** (.010)	-.014 (.015)	-.258 (.189)	-.526 (.285)	-.200 (.236)
China (CN)	-.128** (.043)	-.126*** (.021)	-.062 (.032)	-.844** (.283)	-2.047*** (.239)	-.980*** (.238)
India (IN)	-.165*** (.036)	-.119*** (.029)	-.150*** (.028)	-.793*** (.207)	-1.437*** (.340)	-1.536*** (.151)
Former Soviet Union (FSU)	-.208*** (.015)	-.146*** (.017)	-.126*** (.018)	-1.152*** (.172)	-1.900*** (.200)	-1.610*** (.161)
Rest of the world (RW)	-.131*** (.011)	-.109*** (.008)	-.091*** (.015)	-.759*** (.125)	-1.351*** (.207)	-1.246*** (.174)

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

1. The specifications are the same as for Table 2 except that here we use 5-year windows instead of 2-year windows for forward citations. Note that the last sub-period includes patents granted up to only 2006 to reflect this.

TABLE C.3. Estimation results of the citation lag model for chemical sector

Country	Period							
	1 (1980- 1983)	2 (1984- 1987)	3 (1988- 1991)	4 (1992- 1995)	5 (1996- 1999)	6 (2000- 2003)	7 (2004- 2007)	8 (2008- 2011)
Japan (JP)	-0.15 (0.05)	-0.11 (0.05)	-0.14 (0.05)	-0.02 (0.05)	0.27 (0.05)	0.31 (0.06)	-0.04 (0.09)	0.46 (0.26)
Germany (DE)	-0.32 (0.07)	-0.32 (0.07)	-0.12 (0.07)	-0.12 (0.07)	0.17 (0.07)	0.35 (0.08)	-0.02 (0.15)	-0.30 (0.44)
EU	-0.16 (0.07)	-0.21 (0.07)	-0.16 (0.07)	-0.21 (0.07)	0.12 (0.07)	0.15 (0.08)	-0.35 (0.35)	0.52 (0.37)
France (FR)	-0.12 (0.04)	-0.11 (0.04)	0.06 (0.04)	0.12 (0.03)	0.3 (0.04)	0.33 (0.04)	0.21 (0.07)	0.14 (0.23)
Great Britain (GB)	-0.34 (0.06)	-0.45 (0.06)	-0.34 (0.06)	-0.15 (0.05)	0.18 (0.06)	0.11 (0.06)	-0.15 (0.11)	0.72 (0.42)
Taiwan (TW)	-1.12 (0.29)	-1.26 (0.23)	-0.64 (0.16)	-0.19 (0.11)	0.16 (0.09)	0.18 (0.08)	-0.13 (0.12)	0.1 (0.31)
Korea (KR)	-0.48 (0.23)	-0.92 (0.23)	-0.29 (0.14)	-0.17 (0.11)	0.39 (0.09)	0.5 (0.08)	0.38 (0.13)	0.15 (0.30)
Canada (CA)	-0.26 (0.16)	-0.4 (0.17)	-0.54 (0.3)	-0.29 (0.23)	-0.08 (0.21)	-0.25 (0.27)	-0.46 (0.24)	-1.02 (0.72)
Switzerland (CH)	-0.47 (0.08)	-0.41 (0.07)	-0.11 (0.2)	-0.42 (0.16)	-0.22 (0.16)	-0.08 (0.18)	-0.14 (0.25)	-0.84 (0.72)
Australia (AU)	-0.1 (0.09)	-0.31 (0.11)	-0.28 (0.07)	-0.19 (0.06)	0.12 (0.07)	0.13 (0.08)	-0.61 (0.13)	0.08 (0.33)
Israel (IL)	-0.39 (0.21)	-0.61 (0.2)	0.01 (0.11)	-0.06 (0.11)	0.24 (0.11)	0.33 (0.13)	-0.17 (0.21)	-0.24 (0.52)
China (CN)			-0.48 (0.17)	-0.46 (0.17)	-0.11 (0.17)	0.38 (0.17)	-0.77 (0.27)	0.93 (0.62)
India (IN)			-0.69 (0.31)	-0.44 (0.25)	0.17 (0.2)	-0.11 (0.2)	-0.71 (0.37)	
Former Soviet Union (FSU)	-0.24 (0.25)	-1.28 (0.33)	-0.43 (0.26)	0 (0.22)	0.29 (0.25)	-0.13 (0.24)	0.14 (0.39)	
Rest of the world (RW)	-0.51 (0.1)	-0.49 (0.11)	-0.32 (0.12)	-0.5 (0.1)	-0.09 (0.1)	0.14 (0.11)	-0.32 (0.17)	0.00 (0.45)

Notes: The specifications are the same as for Table 4 except that here only chemical sector patents are considered among the cited patents. We include CN and IN in RW for the first two sub-periods to avoid diverging estimators due to their small sample sizes. For the same reason, IN and FSU are included in RW for the last sub-period.

TABLE C.4. Estimation results of the citation lag model for computers and communications sector

Country	Period							
	1 (1980- 1983)	2 (1984- 1987)	3 (1988- 1991)	4 (1992- 1995)	5 (1996- 1999)	6 (2000- 2003)	7 (2004- 2007)	8 (2008- 2011)
Japan (JP)	-0.34 (0.1)	-0.55 (0.08)	-0.83 (0.08)	-0.95 (0.07)	-0.4 (0.05)	-0.54 (0.04)	-0.4 (0.05)	-0.27 (0.11)
Germany (DE)	-0.76 (0.11)	-0.94 (0.09)	-0.79 (0.09)	-0.92 (0.08)	-0.32 (0.06)	-0.63 (0.06)	-0.46 (0.06)	-0.29 (0.13)
EU	-0.69 (0.11)	-0.82 (0.09)	-0.86 (0.09)	-0.89 (0.08)	-0.53 (0.06)	-0.62 (0.05)	-0.66 (0.05)	-0.32 (0.13)
France (FR)	-0.5 (0.05)	-0.35 (0.04)	-0.28 (0.04)	-0.36 (0.03)	-0.13 (0.02)	-0.3 (0.02)	-0.19 (0.03)	-0.06 (0.07)
Great Britain (GB)	-0.93 (0.12)	-0.83 (0.1)	-1 (0.09)	-1.16 (0.07)	-0.41 (0.05)	-0.59 (0.04)	-0.48 (0.05)	-0.44 (0.14)
Taiwan (TW)	-2.65 (0.63)	-1.96 (0.33)	-1.29 (0.16)	-1 (0.09)	-0.24 (0.05)	-0.5 (0.04)	-0.4 (0.05)	-0.18 (0.1)
Korea (KR)	-2.2 (0.39)	-1.41 (0.26)	-1.16 (0.16)	-0.98 (0.11)	-0.2 (0.07)	-0.3 (0.05)	-0.24 (0.05)	-0.28 (0.11)
Canada (CA)	-0.85 (0.29)	-1.27 (0.28)	-2.76 (0.96)	-0.93 (0.52)	-0.79 (0.32)	-1.06 (0.16)	-0.95 (0.09)	-0.23 (0.15)
Switzerland (CH)	-0.49 (0.14)	-0.77 (0.11)	-1.03 (0.27)	-0.93 (0.22)	-0.37 (0.13)	-0.72 (0.1)	-0.78 (0.1)	-0.51 (0.21)
Australia (AU)	-0.58 (0.21)	-0.25 (0.22)	-1.12 (0.1)	-0.99 (0.08)	-0.42 (0.05)	-0.61 (0.04)	-0.61 (0.05)	-0.45 (0.1)
Israel (IL)	-1.11 (0.32)	-1.3 (0.25)	-0.85 (0.19)	-1.11 (0.18)	-0.41 (0.15)	-0.79 (0.11)	-0.38 (0.13)	0.08 (0.27)
China (CN)			-1.55 (0.17)	-0.9 (0.12)	-0.61 (0.07)	-0.75 (0.06)	-0.69 (0.07)	-0.62 (0.14)
India (IN)			-1.42 (0.82)	0 (0.45)	-0.67 (0.25)	-0.86 (0.11)	-0.72 (0.1)	-0.17 (0.14)
Former Soviet Union (FSU)	0.94 (0.62)	-1.98 (0.64)	-1.61 (0.61)	-1.53 (0.34)	-0.69 (0.25)	-1.16 (0.23)	-0.8 (0.19)	0.22 (0.29)
Rest of the world (RW)	-1.29 (0.24)	-1.23 (0.22)	-1.15 (0.21)	-0.88 (0.15)	-0.61 (0.09)	-0.62 (0.07)	-0.79 (0.08)	-0.59 (0.16)

Notes: The specifications are the same as for Table 4 except that only computers and communications sector patents are considered among the cited patents. We include CN and IN in RW for the first two sub-periods to avoid diverging estimators due to their small sample sizes.

TABLE C.5. Estimation results of the citation lag model for drugs and medical sector

Country	Period							
	1 (1980- 1983)	2 (1984- 1987)	3 (1988- 1991)	4 (1992- 1995)	5 (1996- 1999)	6 (2000- 2003)	7 (2004- 2007)	8 (2008- 2011)
Japan (JP)	-0.4 (0.1)	-0.46 (0.09)	-0.35 (0.07)	-0.74 (0.07)	0.4 (0.06)	0.22 (0.06)	-0.16 (0.13)	0.18 (0.24)
Germany (DE)	-0.59 (0.13)	-0.62 (0.11)	-0.56 (0.1)	-0.73 (0.09)	0.35 (0.08)	0.17 (0.08)	-0.24 (0.16)	-0.18 (0.36)
EU	-0.66 (0.12)	-0.66 (0.11)	-0.41 (0.09)	-0.63 (0.09)	0.33 (0.07)	0.28 (0.08)	-0.19 (0.17)	-0.37 (0.35)
France (FR)	-0.45 (0.08)	-0.38 (0.07)	-0.28 (0.06)	-0.42 (0.07)	0.43 (0.05)	0.38 (0.05)	-0.08 (0.12)	-0.09 (0.32)
Great Britain (GB)	-0.67 (0.1)	-0.74 (0.09)	-0.41 (0.08)	-0.75 (0.07)	0.26 (0.05)	0.1 (0.06)	-0.4 (0.12)	-0.64 (0.31)
Taiwan (TW)	-2.53 (1.31)	-1.52 (0.55)	-0.57 (0.33)	-0.87 (0.22)	0.49 (0.14)	0 (0.12)	-0.21 (0.28)	-0.38 (0.64)
Korea (KR)	-1.45 (0.49)	-0.65 (0.38)	-0.09 (0.23)	-0.6 (0.18)	0.19 (0.12)	0.29 (0.12)	-0.32 (0.26)	-0.94 (0.64)
Canada (CA)	-0.93 (0.26)	-0.26 (0.2)	-0.8 (0.44)	-1.34 (0.47)	-0.19 (0.24)	-0.43 (0.22)	-1.18 (0.59)	0.26 (0.61)
Switzerland (CH)	-0.79 (0.15)	-0.81 (0.13)	-0.57 (0.17)	-0.86 (0.15)	0.25 (0.11)	0.09 (0.12)	-0.4 (0.33)	0.27 (0.52)
Australia (AU)	-0.36 (0.17)	-0.29 (0.16)	-0.73 (0.1)	-0.9 (0.09)	0.18 (0.07)	0.09 (0.07)	-0.51 (0.15)	0.43 (0.36)
Israel (IL)	-0.66 (0.24)	-0.85 (0.21)	-0.73 (0.15)	-0.84 (0.14)	0.54 (0.11)	0.24 (0.13)	-0.47 (0.2)	0.21 (0.33)
China (CN)			-0.38 (0.16)	-0.88 (0.13)	-0.11 (0.09)	-0.05 (0.11)	-0.67 (0.19)	-0.14 (0.31)
India (IN)			-0.4 (0.46)	-1.28 (0.32)	0.28 (0.19)	0.43 (0.2)	-0.53 (0.54)	-0.63 (1.5)
Former Soviet Union (FSU)	-0.72 (0.41)	-0.52 (0.3)	-1.02 (0.38)	-0.43 (0.33)	-0.09 (0.21)	0.19 (0.23)	-0.57 (0.61)	-3.23 (1.43)
Rest of the world (RW)	-0.8 (0.18)	-1.08 (0.18)	-0.6 (0.14)	-0.96 (0.13)	0.05 (0.11)	0.11 (0.11)	-0.64 (0.21)	-0.1 (0.34)

Notes: The specifications are the same as for Table 4 except that only drugs and medical sector patents are considered among the cited patents. We include CN and IN in RW for the first two sub-periods to avoid diverging estimators due to their small sample sizes.

TABLE C.6. Estimation results of the citation lag model for electrical and electronics sector

Country	Period							
	1 (1980- 1983)	2 (1984- 1987)	3 (1988- 1991)	4 (1992- 1995)	5 (1996- 1999)	6 (2000- 2003)	7 (2004- 2007)	8 (2008- 2011)
Japan (JP)	-0.42 (0.05)	-0.2 (0.05)	-0.25 (0.05)	-0.28 (0.05)	-0.24 (0.04)	0.01 (0.04)	-0.01 (0.06)	0.03 (0.12)
Germany (DE)	-0.41 (0.07)	-0.35 (0.06)	-0.19 (0.06)	-0.2 (0.07)	-0.25 (0.07)	0.01 (0.06)	0.09 (0.1)	-0.3 (0.2)
EU	-0.49 (0.07)	-0.28 (0.07)	-0.28 (0.07)	-0.4 (0.07)	-0.21 (0.07)	0 (0.06)	-0.02 (0.1)	-0.32 (0.34)
France (FR)	-0.33 (0.04)	-0.11 (0.03)	-0.07 (0.03)	-0.08 (0.03)	0.05 (0.03)	0.11 (0.02)	0.11 (0.03)	0.09 (0.09)
Great Britain (GB)	-0.64 (0.07)	-0.4 (0.06)	-0.4 (0.06)	-0.31 (0.06)	-0.33 (0.05)	-0.13 (0.05)	-0.19 (0.06)	-0.06 (0.15)
Taiwan (TW)	-1.71 (0.22)	-1.07 (0.16)	-0.47 (0.1)	-0.33 (0.07)	-0.04 (0.05)	-0.02 (0.04)	0 (0.05)	0.07 (0.12)
Korea (KR)	-1.22 (0.17)	-0.87 (0.13)	-0.52 (0.09)	-0.29 (0.06)	-0.02 (0.04)	0.19 (0.03)	0.11 (0.05)	0.24 (0.12)
Canada (CA)	-0.41 (0.18)	-0.71 (0.18)	-0.91 (0.41)	-1.32 (0.35)	-0.77 (0.28)	-0.44 (0.13)	-0.37 (0.1)	-0.05 (0.15)
Switzerland (CH)	-0.63 (0.09)	-0.44 (0.08)	-0.71 (0.19)	-0.57 (0.21)	-0.33 (0.19)	-0.49 (0.15)	0.07 (0.25)	0.4 (0.9)
Australia (AU)	-0.35 (0.11)	-0.42 (0.11)	-0.45 (0.07)	-0.5 (0.07)	-0.34 (0.06)	-0.07 (0.06)	-0.21 (0.09)	-0.23 (0.19)
Israel (IL)	-1.3 (0.27)	-1.03 (0.17)	-0.38 (0.12)	-0.39 (0.12)	-0.13 (0.15)	-0.24 (0.11)	0.13 (0.14)	0.22 (0.28)
China (CN)			-0.55 (0.13)	-0.58 (0.13)	-0.32 (0.11)	-0.28 (0.1)	-0.14 (0.12)	0.28 (0.34)
India (IN)			-1.7 (0.66)	-0.79 (0.47)	-1.25 (0.31)	-0.66 (0.15)	-0.24 (0.16)	-0.65 (0.3)
Former Soviet Union (FSU)	-0.21 (0.28)	-0.53 (0.36)	-0.05 (0.31)	-0.11 (0.3)	-0.26 (0.2)	-0.06 (0.18)	-0.16 (0.28)	-1.89 (1.29)
Rest of the world (RW)	-0.86 (0.15)	-0.8 (0.13)	-0.74 (0.13)	-0.61 (0.11)	-0.36 (0.08)	-0.12 (0.06)	-0.3 (0.09)	0.13 (0.19)

Notes: The specifications are the same as forh Table 4 except that only electrical and electronics sector patents are considered among the cited patents. We include CN and IN in RW for the first two sub-periods to avoid diverging estimators due to their small sample sizes.

TABLE C.7. Estimation results of the citation lag model for mechanical sector

Country	Period							
	1 (1980- 1983)	2 (1984- 1987)	3 (1988- 1991)	4 (1992- 1995)	5 (1996- 1999)	6 (2000- 2003)	7 (2004- 2007)	8 (2008- 2011)
Japan (JP)	-0.31 (0.04)	-0.15 (0.04)	-0.06 (0.04)	-0.18 (0.04)	0.04 (0.04)	0.18 (0.04)	-0.05 (0.09)	0.03 (0.15)
Germany (DE)	-0.39 (0.07)	-0.24 (0.06)	0.03 (0.07)	-0.21 (0.07)	-0.01 (0.07)	0.16 (0.08)	-0.14 (0.13)	-0.27 (0.44)
EU	-0.27 (0.06)	-0.14 (0.06)	-0.08 (0.07)	-0.29 (0.07)	-0.04 (0.07)	0.09 (0.08)	-0.09 (0.12)	0.21 (0.28)
France (FR)	-0.28 (0.04)	-0.1 (0.03)	0.07 (0.03)	0 (0.03)	0.1 (0.03)	0.23 (0.03)	0.19 (0.06)	0.13 (0.12)
Great Britain (GB)	-0.46 (0.06)	-0.24 (0.05)	-0.17 (0.06)	-0.27 (0.05)	-0.03 (0.05)	0.06 (0.05)	0.07 (0.09)	-0.42 (0.24)
Taiwan (TW)	-1.19 (0.23)	-0.81 (0.2)	-0.59 (0.15)	-0.39 (0.1)	0.07 (0.08)	0.23 (0.09)	0.15 (0.1)	0.16 (0.23)
Korea (KR)	-1.12 (0.14)	-0.63 (0.1)	-0.39 (0.09)	-0.17 (0.07)	0.09 (0.06)	0.23 (0.05)	0.23 (0.09)	-0.09 (0.18)
Canada (CA)	-0.52 (0.13)	-0.45 (0.13)	-1.52 (0.47)	-1 (0.37)	-1.07 (0.35)	-0.38 (0.19)	-0.21 (0.21)	-0.43 (0.32)
Switzerland (CH)	-0.5 (0.07)	-0.4 (0.06)	-0.46 (0.13)	-0.38 (0.13)	-0.07 (0.13)	-0.22 (0.12)	-0.38 (0.22)	-0.52 (0.63)
Australia (AU)	-0.33 (0.09)	-0.21 (0.09)	-0.26 (0.06)	-0.29 (0.05)	-0.1 (0.05)	0.09 (0.05)	-0.24 (0.1)	-0.15 (0.21)
Israel (IL)	-0.89 (0.19)	-0.49 (0.17)	0.02 (0.1)	-0.35 (0.11)	-0.08 (0.1)	0.18 (0.11)	-0.34 (0.23)	1.13 (0.58)
China (CN)			-0.08 (0.15)	-0.34 (0.15)	-0.12 (0.15)	0.1 (0.15)	-0.23 (0.21)	-0.36 (0.57)
India (IN)			-1.21 (0.82)	1.4 (1.12)	-0.89 (0.48)	-0.61 (0.42)	-0.97 (0.79)	
Former Soviet Union (FSU)	-0.5 (0.27)	-0.53 (0.32)	-0.35 (0.27)	-0.28 (0.25)	0.3 (0.28)	0.1 (0.27)	-0.77 (0.86)	
Rest of the world (RW)	-0.68 (0.11)	-0.3 (0.11)	-0.47 (0.12)	-0.37 (0.1)	-0.14 (0.09)	-0.15 (0.09)	0.01 (0.14)	-0.18 (0.32)

Notes: The specifications are the same as for Table 4 except that only mechanical sector patents are considered among the cited patents. We include CN and IN in RW for the first two sub-periods to avoid diverging estimators due to their small sample sizes. For the same reason, IN and FSU are included in RW for the last sub-period.

TABLE C.8. Estimation results of the citation lag model for other sectors

Country	Period							
	1 (1980- 1983)	2 (1984- 1987)	3 (1988- 1991)	4 (1992- 1995)	5 (1996- 1999)	6 (2000- 2003)	7 (2004- 2007)	8 (2008- 2011)
Japan (JP)	-0.14 (0.05)	-0.1 (0.04)	0.05 (0.05)	-0.11 (0.05)	0.16 (0.04)	0.31 (0.05)	-0.11 (0.08)	0.19 (0.22)
Germany (DE)	-0.13 (0.06)	-0.09 (0.06)	0 (0.06)	-0.07 (0.07)	0.09 (0.07)	0.32 (0.07)	0.01 (0.12)	-0.87 (0.37)
EU	-0.25 (0.06)	-0.11 (0.06)	-0.22 (0.06)	-0.19 (0.06)	0.1 (0.06)	0.21 (0.06)	-0.14 (0.1)	0.09 (0.24)
France (FR)	-0.17 (0.04)	0.04 (0.04)	0.12 (0.04)	-0.01 (0.04)	0.27 (0.04)	0.38 (0.04)	0.23 (0.06)	0.31 (0.17)
Great Britain (GB)	-0.35 (0.05)	-0.15 (0.05)	-0.14 (0.05)	-0.16 (0.05)	0.13 (0.05)	0.33 (0.05)	0.13 (0.08)	0.06 (0.2)
Taiwan (TW)	-0.92 (0.19)	-0.99 (0.18)	-0.36 (0.13)	-0.33 (0.1)	0.11 (0.08)	0.16 (0.1)	-0.05 (0.11)	0.27 (0.26)
Korea (KR)	-0.73 (0.12)	-0.55 (0.08)	-0.15 (0.06)	-0.04 (0.06)	0.26 (0.05)	0.44 (0.05)	0.08 (0.08)	0.48 (0.22)
Canada (CA)	-0.58 (0.1)	-0.16 (0.1)	0.22 (0.36)	-1.37 (0.37)	-0.31 (0.22)	-0.14 (0.18)	-0.26 (0.17)	0.54 (0.3)
Switzerland (CH)	-0.42 (0.05)	-0.31 (0.05)	-0.25 (0.1)	-0.25 (0.1)	0.05 (0.09)	-0.01 (0.11)	-0.25 (0.18)	0.41 (0.42)
Australia (AU)	-0.29 (0.09)	-0.04 (0.09)	-0.22 (0.04)	-0.21 (0.04)	0.07 (0.04)	0.1 (0.04)	-0.24 (0.07)	-0.1 (0.24)
Israel (IL)	-0.68 (0.16)	-0.38 (0.16)	0.08 (0.1)	-0.03 (0.11)	0.26 (0.1)	0.17 (0.13)	0.07 (0.19)	0.54 (0.75)
China (CN)			-0.27 (0.14)	-0.21 (0.14)	0.07 (0.13)	0.51 (0.18)	-0.51 (0.23)	-0.13 (0.56)
India (IN)			-0.8 (0.7)	-2.08 (0.68)	-0.44 (0.41)	-0.53 (0.33)	0.52 (0.73)	
Former Soviet Union (FSU)	0.18 (0.31)	-0.59 (0.31)	0.08 (0.32)	-0.82 (0.34)	-0.04 (0.32)	0.07 (0.29)	0.04 (0.44)	
Rest of the world (RW)	-0.4 (0.09)	-0.45 (0.08)	-0.3 (0.09)	-0.43 (0.08)	-0.04 (0.07)	0.04 (0.07)	-0.04 (0.1)	0.02 (0.26)

Notes: The specifications are the same as for Table 4 except that only patents not categorized as the aforementioned five sectors are considered among the cited patents. We include CN and IN in RW for the first two sub-periods to avoid diverging estimators due to their small sample sizes. For the same reason, IN and FSU are included in RW for the last sub-period.

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